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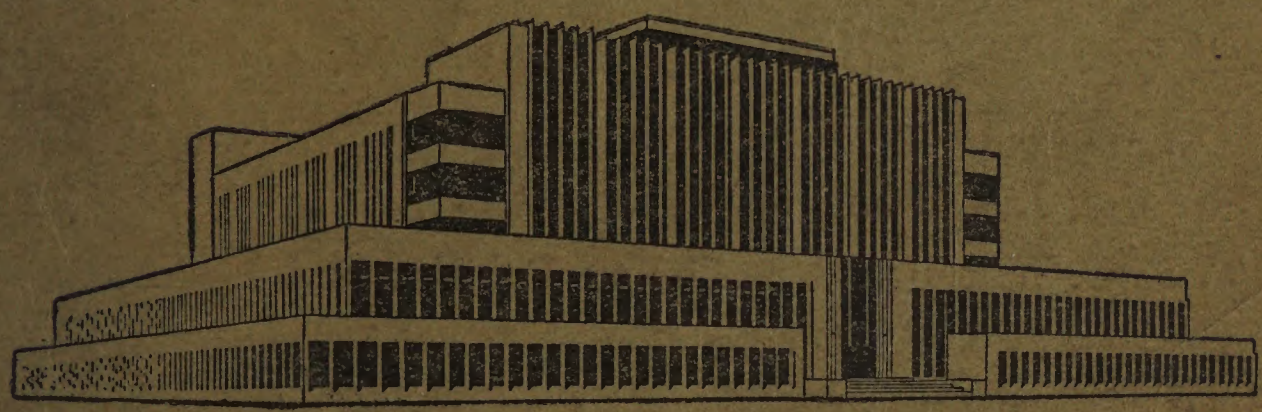
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UNITED STATES DEPARTMENT OF AGRICULTURE

WASHINGTON, D. C.

WOOD HANDBOOK

Basic Information on Wood as a Material of Construction with Data for Its Use in Design and Specifications



The Forest Products Laboratory

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FOREST RESEARCH - FOREST SERVICE

[Issued September 1935]

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This handbook was prepared by R. F. Luxford and George W. Trayer with the assistance of other members of the Forest Products Laboratory. It is based chiefly upon the accumulation of information that has resulted from engineering investigations and allied studies conducted by the Laboratory during the past 20 years. Other sources of information have also been drawn upon freely. The following are among the members of the Laboratory staff who have materially assisted in its preparation: J. M. Gahagan, Arthur Koehler, W. K. Loughborough, L. J. Markwardt, J. S. Mathewson, J. A. Newlin, J. A. Scholten, C. V. Sweet, L. V. Teesdale, Rolf Thelen, and T. R. C. Wilson; the section on Painting and Finishing Wood was prepared by F. L. Browne, that on Wood Preservation by G. M. Hunt, that on Lumber Grades and Sizes by E. M. Davis, and that on Glued Wood Construction by T. R. Truax. The section on Mold, Stain, and Decay was prepared by C. Audrey Richards, Bureau of Plant Industry. Assistance in the development and critical review of the manuscript was received from H. S. Betts, Division of Forest Products, Forest Service. Valuable assistance was also received from various architects, engineers, manufacturers, and users of wood. The abundance of assistance so received makes impractical separate acknowledgments.

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WOOD HANDBOOK

Basic Information on Wood as a Material of Construction with Data for Its Use in Design and Specification

By *Forest Products Laboratory*,[1] *Forest Research, Forest Service*

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GLOSSARY

Air-dried. (See Seasoning.)

American lumber standards. American lumber standards embody provisions for softwood lumber dealing with recognized classifications, nomenclature, basic grades, seasoning standards, sizes, uniform workings, description, measurement, tally, shipping provisions, grade marking, tally cards, and inspection of lumber. The primary purpose of these standards is to serve as a guide or basic examples in the preparation or revision of the grading rules of the various lumber manufacturers' associations; their use as a framework for such rules will eliminate differences often existing. A purchaser in order to buy in conformity with American lumber standards must make use of association rules that are in conformity with them, as the basic standards are not in themselves commercial rules.

Annual growth ring. (See Ring, annual growth.)

Bastard sawn. Hardwood lumber in which the annual rings make angles of 30° to 60° with the surface of the piece.

Beams and stringers. Large pieces (nominal dimensions 5 by 8 inches and up) of rectangular cross section graded with respect to their strength in bending when loaded on the narrow face.

Birdseye. A small central spot with the wood fibers arranged around it in the form of an ellipse so as to give the appearance of an eye.

Blemish. Anything, not necessarily a defect, marring the appearance of wood.

Blue stain. (See Stain, blue.)

Boards. (See Lumber.)

Bow. That distortion of a board in which the face is convex or concave longitudinally.

Boxed heart. The term used when the pith falls entirely within the four faces anywhere in the length of a piece.

Brashness. A condition of wood characterized by low resistance to shock and by an abrupt failure across the grain without splintering.

Broad-leaved trees. (See Hardwoods.)

Brown stain. (See Stain, brown.)

Burl. A large wartlike excrescence on a tree trunk. It contains the dark piths of a large number of buds which rarely develop. The formation of a burl apparently results from an injury to the tree.

Cambium. The layer of tissue just beneath the bark from which the new wood and bark cells of each year's growth develop.

Cell. A general term for the minute units of wood structure. It includes fibers, vessel segments, and other elements of diverse structure and functions.

Cellulose. The carbohydrate that is the principal constituent of wood and forms the framework of the cells.

Check. A lengthwise separation of the wood, the greater part of which occurs across the rings of annual growth.

Chemical brown stain. (See Stain, chemical brown.)

Close-grained wood. (See Grain.)

Coarse-grained wood. (See Grain.)

Collapse. The flattening of single cells or rows of cells in heartwood during the drying or pressure treatment of wood, characterized externally by a caved-in or corrugated appearance.

Compartment kiln. (See Kiln.)

Compression wood. Abnormal wood that often forms on the lower side of branches and of leaning trunks of softwood trees. Compression wood is identified by its relatively wide annual rings, usually eccentric, and its relatively large amount of summer wood, usually more than 50 percent of the width of the annual rings in which it occurs. Compression wood shrinks excessively lengthwise as compared with normal wood.

Conifer. (See Softwoods.)

Crook. That distortion of a board in which the edge is convex or concave longitudinally.

Crossband. To place the grain of layers of wood at right angles in order to minimize shrinking and swelling and consequent warping; also the layer of veneer at right angles to the face plies.

Cross break. A separation of the wood cells across the grain. Such breaks may be due to internal strains resulting from unequal longitudinal shrinkage or to external forces.

Cross grain. (See Grain.)

Cup. The distortion of a board in which the face is convex or concave transversely.

Decay. Disintegration of wood substance through the action of wood-destroying fungi.

Incipient decay. The early stage of decay in which the disintegration has not proceeded far enough to soften or otherwise impair the hardness of the wood perceptibly.

Typical or advanced decay. The stage of decay in which the disintegration is readily recognized because the wood has become punky, soft and spongy, stringy, pitted, or crumbly.

Defect. Any irregularity occurring in or on wood that may lower its strength.

Density. The mass of a body per unit volume. When expressed in the metric system, it is numerically equal to the specific gravity of the same substance.

Density rule. Rules for estimating the density of wood based on percentage of summer wood and rate of growth. The rules at present apply only to southern yellow pine and Douglas fir and differ slightly.

Diagonal grain. (See Grain.)

Diamond. A distortion in drying that causes a piece of wood originally rectangular in cross section to become diamond-shaped.

Diffuse-porous woods. Hardwoods in which the pores are practically uniform in size throughout each annual ring, or decrease slightly toward the outer border of the ring.

Dimension. (See Lumber.)

Dimension stock. Squares or flat stock usually in pieces under the minimum sizes admitted in standard lumber grades, rough or dressed, green or dry, cut to the approximate dimensions required for the various products of woodworking factories.

Dote. "Dote", "doze", and "rot" are synonymous with "decay", and are any form of decay which may be evident as either a discoloration or a softening of the wood.

Dry rot. A term loosely applied to many types of decay but especially to that which, when in an advanced stage, permits the wood to be easily crushed to a dry powder. The term is actually a misnomer for any decay, since all fungi require considerable moisture for growth.

Durability. A general term for permanence or lastingness. Frequently used to refer to the degree of resistance of a species or of an individual piece of wood to attack by wood-destroying fungi under conditions that favor such attack. In this connection the term "resistance to decay" is more specific.

Edge grain. (See Grain.)

Empty-cell process. Any process for impregnating wood with preservatives or chemicals in which air is imprisoned in the wood under the pressure of the entering preservative and then expands, when the pressure is released, to drive out part of the injected preservative.

Encased knot. (See Knot.)

Extractives. Substances in wood, not an integral part of the cellular structure, that can be dissolved out with hot or cold water, ether, benzene, or other relatively inert solvents.

Equilibrium moisture content. The moisture content at which wood neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature.

Factory and shop lumber. (See Lumber.)

Fiber. A wood fiber is a comparatively long (one-twenty-fifth or less to one-third inch), narrow, tapering cell closed at both ends.

Fiber-saturation point. The stage in the drying or in the wetting of wood at which the cell walls are saturated and the cell cavities are free from water.

Figure. The pattern produced in a wood surface by irregular coloration and by annual growth rings, rays, knots, and such deviations from regular grain as interlocked and wavy grain.

Flakes. (See Rays, wood.)

Flat grain. (See Grain.)

Flitch. A thick piece of lumber with wane (bark) on one or more edges.

Full-cell process. Any process for impregnating wood with preservatives or chemicals in which a vacuum is drawn to remove air from the wood before admitting the preservative.

Grade. The designation of the quality of a manufactured piece of wood.

Grain. The direction, size, arrangement, appearance, or quality of the fibers in wood.

Close-grained wood. Wood with narrow and inconspicuous annual rings. The term is sometimes used to designate wood having small and closely spaced pores, but in this sense the term "fine textured" is more often used.

Coarse-grained wood. Wood with wide and conspicuous annual rings; that is, rings in which there is considerable difference between spring wood and summer wood. The term is sometimes used to designate wood with large pores, such as oak, ash, chestnut, and walnut, but in this sense the term "coarse textured" is more often used.

Cross grain. Grain not parallel with the axis of a piece. It may be either diagonal or spiral grain or a combination of the two.

Diagonal grain. Annual rings at an angle with the axis of a piece as a result of sawing at an angle with the bark of the tree.

Edge grain. Edge-grain lumber has been sawed parallel with the pith of the log and approximately at right angles to the growth rings; that is, the rings form an angle of 45° or more with the surface of the piece.

Flat grain. Flat-grain lumber has been sawed parallel with the pith of the log and approximately tangent to the growth rings; that is, the rings form an angle of less than 45° with the surface of the piece.

Interlocked-grained wood. Wood in which the fibers are inclined in one direction in a number of rings of annual growth, then gradually reverse and are inclined in an opposite direction in succeeding growth rings, then reverse again.

Open-grained wood. Common classification of painters for woods with large pores, such as oak, ash, chestnut, and walnut. Also known as "coarse textured."

Plain-sawed. Another term for flat grain.

Quarter-sawed. Another term for edge grain.

Spiral grain. A type of growth in which the fibers take a spiral course about the bole of a tree instead of the normal vertical course. The spiral may extend right-handed or left-handed around the tree trunk.

Vertical grain. Another term for edge grain.

Wavy-grained wood. Wood in which the fibers collectively take the form of waves or undulations.

Green. Unseasoned, wet.

Growth ring. (See Ring, annual growth.)

Hardwoods. The botanical group of trees that are broadleaved. The term has no reference to the actual hardness of the wood. Angiosperms is the botanical name for hardwoods.

Heart, Heartwood. The wood, extending from the pith to the sapwood, the cells of which no longer participate in the life processes of the tree. Heartwood may be infiltrated with gums, resins, and other materials which usually make it darker and more decay-resistant than sapwood.

Honeycomb. Checks, often not visible at the surface, that occur in the interior of a piece, usually along the wood rays.

Imperfect manufacture. Includes all defects or blemishes which are produced in manufacturing, such as chipped grain, loosened grain, raised grain, torn grain, skips in dressing, hit and miss, variation in sawing, miscut lumber, machine burn, machine gouge, mismatching, and insufficient tongue or groove.

Interlocked grained wood. (See Grain.)

Joist and plank. Pieces (nominal dimensions 2 to 4 inches in thickness by 4 inches and wider) of rectangular cross section graded with respect to their strength in bending when loaded either on the narrow face as joist or on the wide face as plank.

Kiln. A heated chamber for drying lumber.

Compartment kiln. A dry kiln designed to keep the same temperature and relative humidity throughout at any given time. In it the entire charge of lumber is dried as a unit, under drying conditions that increase in severity during the operation.

Progressive kiln. A dry kiln designed to provide drying conditions that increase in severity from entrance to exit. In it the unit charge is only a part of the total charge of lumber; a unit of perhaps four truck loads is moved through the kiln in a chain of several units, from day to day, with a single unit leaving and another entering at a time.

Kiln brown stain. (See Stain, chemical brown.)

Kiln dried. (See Seasoning.)

Knot. That portion of a branch or limb that has become incorporated in the body of a tree.

Decayed knot. A knot which, due to advanced decay, is not so hard as the surrounding wood.

Encased knot. A knot whose rings of annual growth are not intergrown with those of the surrounding wood.

Intergrown knot. A knot whose rings of annual growth are completely intergrown with those of the surrounding wood.

Round knot. A knot whose sawn section is oval or circular.

Sound knot. A knot which is solid across its face and which is as hard as the surrounding wood.

Spike knot. A knot sawn in a lengthwise direction.

Laminated wood. A piece of wood built up of plies or laminations that have been joined either with glue or with mechanical fastenings. The term is most frequently applied where the plies are too thick to be classified as veneer and when the grain of all plies is parallel.

Lignin. A principal constituent of wood, second in quantity to cellulose. It incrusts the cell walls and cements the cells together.

Lumber. The product of the saw and planing mill not further manufactured than by sawing, resawing, and passing lengthwise through a standard planing machine, crosscut to length and matched.

Factory and shop lumber. Lumber intended to be cut up for use in further manufacture. It is graded on the basis of the percentage of the area which will produce a limited number of cuttings of a specified, or a given minimum, size and quality.

Yard lumber. Lumber that is less than 5 inches in thickness and is intended for general building purposes.

Boards. Yard lumber less than 2 inches thick, 8 inches or more in width.

Dimension. All yard lumber except boards, strips, and timbers; that is, yard lumber 2 inches and less than 5 inches thick, and of any width.

Strips. Yard lumber less than 2 inches thick and less than 8 inches wide.

Millwork. Generally all building materials made of finished wood and manufactured in millwork plants and planing mills are included under the term "millwork." It includes such items as inside and outside doors, window and door frames, blinds, porch work, mantels, panel work, stairways, moldings, and interior trim. It does not include flooring, ceiling, or siding.

Moisture content of wood. Weight of the water contained in the wood usually expressed in percentage of the weight of the oven-dry wood.

Moisture gradient. A condition of graduated moisture content between the successive layers of a material, such as wood, due to the losing or absorbing of moisture. During seasoning the gradations are between the moisture content of the relatively dry surface layers and the wet layers at the center of the piece.

Open grained wood. (See Grain.)

Peck. Pockets or areas of disintegrated wood caused by advanced stages of localized decay in the living tree. It is usually associated with cypress and incense cedar. There is no further development of peck once the lumber is seasoned.

Pitch pocket. An opening extending parallel to the annual rings of growth usually containing, or which has contained, pitch, either solid or liquid.

Pith. The small soft core occurring in the structural center of a log.

Plywood. A piece of wood made of three or more layers of veneer joined with glue and usually laid with the grain of adjoining plies at right angles. Almost always an odd number of plies are used to secure balanced construction.

Plain-sawed. (See Grain.)

Planing mill products. Products worked to pattern, such as flooring, ceiling, and siding.

Pocket rot. Advanced decay which appears in the form of a hole, pocket, or area of soft rot usually surrounded by apparently sound wood.

Pore. (See Vessel.)

Posts and timbers. Pieces of square or approximately square cross section, 4 by 4 inches or larger in nominal dimensions graded primarily for use as posts or columns but adapted to miscellaneous uses in which strength in bending is not especially important.

Preservative. Any substance that, for a reasonable length of time, will prevent the action of wood-destroying fungi, borers of various kinds, and similar destructive life when the wood has been properly coated or impregnated with it.

Progressive kiln. (See Kiln.)

Quarter-sawed. (See Grain.)

Radial. Coincident with a radius from the axis of the tree or log to the circumference.

Rate of growth. The rate at which a tree has laid on wood, measured radially in the trunk or in lumber cut from the trunk. The unit of measure in use is number of annual growth rings per inch.

Rays, wood. Strips of cells extending radially within a tree and varying in height from a few cells in some species to 4 inches or more in oak. The rays serve primarily to store food and transport it horizontally in the tree.

Ring, annual growth. The growth layer put on in a single growth year.

Ring-porous woods. A group of hardwoods in which the pores are comparatively large at the beginning of each annual ring and decrease in size more or less abruptly toward the outer portion of the ring, thus forming a distinct inner zone of pores known as the spring wood and the outer zone with smaller pores known as the summer wood.

Rot. (See Decay.)

Rotary-cut veneer. (See Veneer.)

Sap. All the fluids in a tree, special secretions and excretions, such as gum, excepted.

Sapwood. The layers of wood next to the bark, usually lighter in color than the heartwood, one-half inch to 3 or more inches wide that are actively involved in the life processes of the tree. Under most conditions sapwood is more susceptible to decay than heartwood; as a rule, it is more permeable to liquids than heartwood. Sapwood is not essentially weaker or stronger than heartwood of the same species.

Sawed veneer. (See Veneer.)

Seasoning. Removing moisture from green wood in order to improve its serviceability.

Air-dried or air seasoned. Dried by exposure to the air, usually in a yard, without artificial heat.

Kiln dried. Dried in a kiln with the use of artificial heat.

Second growth. Timber that has grown after the removal by any means of all or a large portion of the previous stand.

Shake. A separation along the grain, the greater part of which occurs between the rings of annual growth.

Shop lumber. (See Lumber.)

Side cut. The term used when the pith is not present in a piece.

Sliced veneer. (See Veneer.)

Softwoods. The botanical group of trees that have needle or scalelike leaves and are evergreen for the most part, cypress, larch, and tamarack being exceptions. The term has no reference to the actual hardness of the wood. Softwoods are often referred to as conifers, and botanically they are called gymnosperms.

Specific gravity. The ratio of the weight of a body to the weight of an equal volume of water at some standard temperature.

Spiral grain. (See Grain.)

Split. A lengthwise separation of the wood, due to the tearing apart of the wood cells.

Spring wood. The portion of the annual growth ring that is formed during the early part of the season's growth. It is usually less dense and weaker mechanically than summer wood.

Stain, blue. A bluish or grayish discoloration of the sapwood caused by the growth of certain moldlike fungi on the surface and in the interior of the piece; made possible by the same conditions that favor the growth of other fungi.

Stain, brown. A rich brown to deep chocolate-brown discoloration of the sapwood of some pines caused by a fungus that acts similarly to the blue-stain fungus.

Stain, chemical brown. A chemical discoloration of wood, which sometimes occurs during the air drying or the kiln drying of several species, apparently caused by the oxidation of extractives.

Stain, sap. (See Stain, blue.)

Strength. The term in its broader sense embraces collectively all the properties of wood which enable it to resist different forces or loads. In its more restricted sense, strength may apply to any one of the mechanical properties, in which event the name of the property under consideration should be stated, thus strength in compression parallel to the grain, strength in bending, hardness, etc.

Strips. (See Lumber.)

Structural timber. Pieces of wood of relatively large size in which strength is the controlling element in their selection and use. Trestle timbers (stringers, caps, posts, sills, bracing, bridge ties, guard rails); car timbers (car framing, including upper framing, car sills); framing for buildings (posts, sills, girders, framing joists); ship timbers (ship timbers, ship decking); and cross arms for poles are examples of structural timbers.

Summer wood. The portion of the annual growth ring that is formed during the latter part of the yearly growth period. It is usually more dense and stronger mechanically than spring wood.

Tangential. Strictly, coincident with a tangent at the circumference of a tree or log, or parallel to such a tangent. In practice, however, it often means roughly coincident with a growth ring.

Texture. A term often used interchangeably with grain. In this handbook it refers to the finer structure of the wood (see Grain) rather than the annual rings.

Timber, standing. Timber still on the stump.

Timbers. Lumber 5 inches or larger in least dimension.

Timbers, round. Timbers used in the original round form, such as poles, piling, and mine timbers.

Tracheid. The elongated cells that constitute the greater part of the structure of the softwoods (frequently referred to as fibers). Also a portion of some hardwoods.

Twist. A distortion caused by the turning or winding of the edges of a board so that the four corners of any face are no longer in the same plane.

Veneer. Thin sheets of wood.

Rotary-cut veneer. Veneer cut in a continuous strip by rotating a log against the edge of a knife in a lathe.

Sawed veneer. Veneer produced by sawing.

Sliced veneer. Veneer that is sliced off by moving a log, bolt, or flitch against a large knife.

Vertical grain. (See Grain.)

Vessels. Wood cells of comparatively large diameter which have open ends and are set one above the other forming continuous tubes. The openings of the vessels on the surface of a piece of wood are usually referred to as pores.

Virgin growth. The original growth of mature trees.

Wane. Bark, or lack of wood or bark, from any cause, on edge or corner of a piece.

Warp. Any variation from a true or plane surface. Warp includes bow, crook, cup, and twist, or any combination thereof.

Wavy-grained wood. (See Grain.)

Weathering. The mechanical or chemical disintegration and discoloration of the surface of wood that is caused by exposure to light, the action of dust and sand carried by winds, and the alternate shrinking and swelling of the surface fibers that come with the continual variation in moisture content brought by changes in the weather. Weathering does not include decay.

Wood preservative. (See Preservative.)

Workability. The degree of ease and smoothness of cut obtainable with hand or machine tools.

Working of wood. Change in the dimensions of a piece of wood with change in moisture content.

Yard brown stain. (See Stain, chemical brown.)

Yard lumber. (See Lumber.)

STRUCTURE OF WOOD

BARK, WOOD, AND PITH

A cross section of a tree trunk shows the following well-defined features in succession from the outside to the center: (1) Bark (fig. 1), which may be divided into (*a*) the outer, corky, dead portion that varies greatly in thickness, and (*b*) the thin, inner, living portion; (2) wood, which in most species is clearly differentiated into sapwood and heartwood; and (3) the pith, a small spot at the center, usually darker in color (Roth).[2] For the most practical purposes the pith is considered a part of the wood.

Between the bark and the wood is a thin layer, invisible without a microscope, called the cambium, in which all growth in thickness of bark and wood takes place (fig. 1). No growth in either diameter or length takes place in wood already formed; new growth is purely the addition of new layers, not the development of old ones (Eames and MacDaniels, and Jeffrey).

Most branches originate at the pith, and consequently their bases gradually become surrounded by the wood of the growing trunk. These enclosed portions of the branches constitute the knots. The lower branches of a forest tree die and later drop off as the tree grows in size. The dead stubs become overgrown by new wood and form loose knots. Knots vary in character even in the same tree, between trees of the same species, and between species according to growth and inherent species characteristics.

GROWTH RINGS

Each year, by growth in the cambium, a tree adds a layer of wood on the outside of that previously formed, thereby increasing the diameter of the trunk and pushing the bark outward. If growth is interrupted each year, by cold weather or dry seasons, the character of the cells at the end of each year's growth and the beginning of the next is sufficiently different to define sharply the annual layers or growth rings (fig. 2). Consequently the age of such a tree may be determined by counting the number of annual rings at its base. In parts of the Tropics, where tree growth is continuous throughout the year, no well-defined annual growth layers are formed and it is impossible, with any degree of accuracy, to tell the age of such trees. (Eames and MacDaniels, Koehler's The Properties and Uses of Woods, and Roth.)

If the growth of a tree is interrupted during the growing season as a result of drought or defoliation by insects, two or even more differentiated rings may be formed in the same season. The inner one in such event usually does not have a sharply defined outer boundary; it is called a false ring.

[2] For further information, the references at the end of this section should be consulted.

Occasionally, under unfavorable conditions, no growth takes place in parts of a tree trunk, especially in the lower portion. In such a case the annual growth layer is incomplete, portions being entirely missing.

SPRING WOOD AND SUMMER WOOD

In many species of wood each annual ring is divided more or less distinctly into two layers. The inner one, the spring wood, consists of cells having relatively large cavities and frequently thin

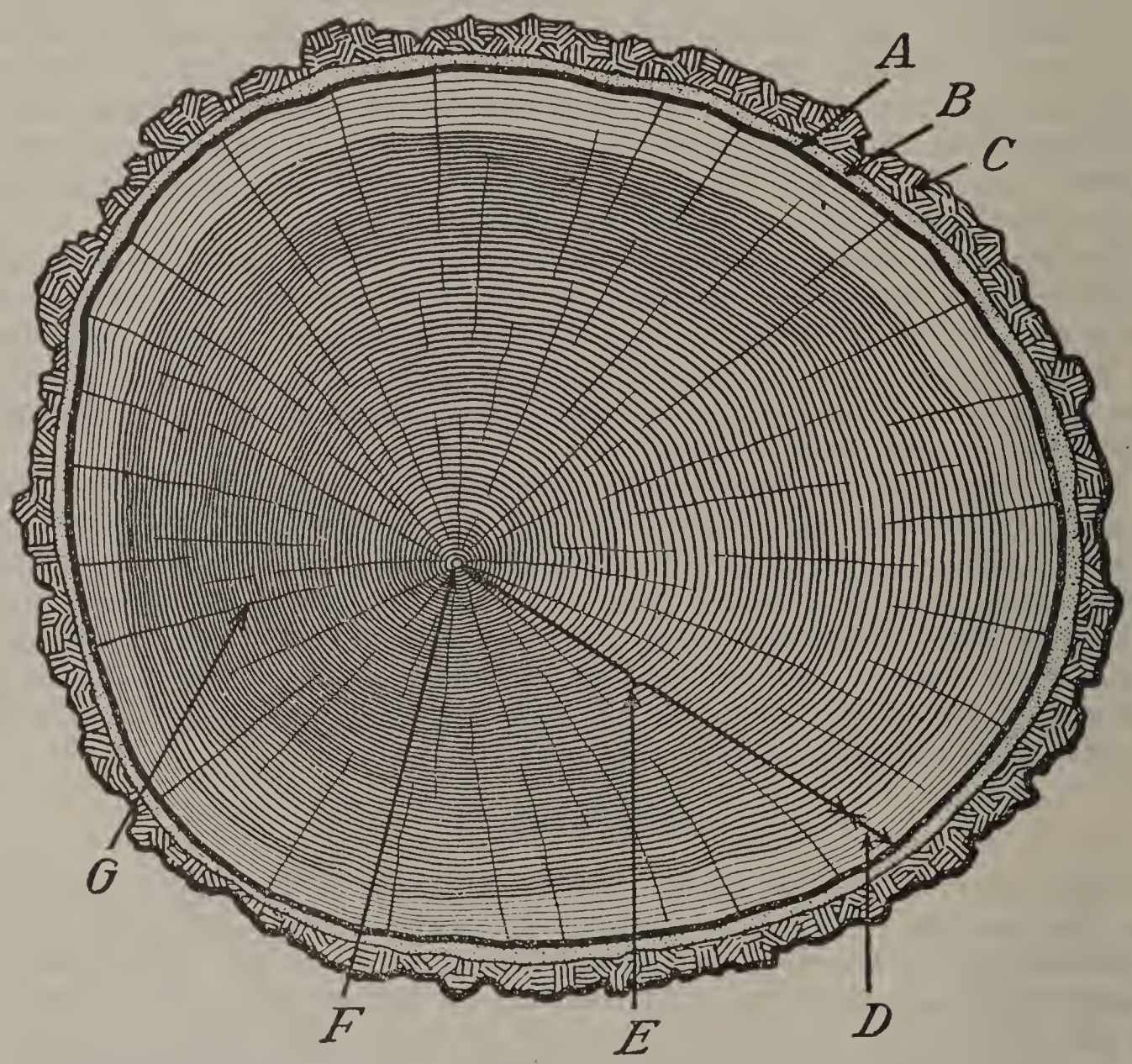


FIGURE 1.—The tree trunk: *A*, Cambium layer (microscopic) is inside of inner bark and forms wood and bark cells. *B*, Inner bark is moist and soft. Carries prepared food from leaves to all growing parts of tree. *C*, Outer bark or corky layer is composed of dry dead tissue. Gives general protection against external injuries. *D*, Sapwood is the light-colored wood beneath the bark. Carries sap from roots to leaves. *E*, Heartwood (inactive) is formed by a gradual change in the sapwood. Gives the tree strength. *F*, Pith is the soft tissue about which the first wood growth takes place in the newly formed twigs. *G*, Wood rays connect the various layers from pith to bark for storage and transference of food.

walls. The outer layer, the summer wood, is composed of smaller cells (fig. 2). The transition from spring wood to summer wood may be either abrupt or gradual, depending on the kind of wood and the growing conditions at the time it was formed.

In most species spring wood differs from summer wood in physical properties. It is lighter in weight, softer, and weaker; it shrinks less across and more along the grain; and it is brash in both softwoods and hardwoods.

In some species of wood, such as the maples, gums, and yellow poplar, there is no appreciable difference in the structure and properties of the wood formed early and later in the season (Koehler's Guidebook).

SAPWOOD AND HEARTWOOD

The sapwood contains living cells and takes an active part in the life processes of the tree. The heartwood consists entirely of inactive tissue and serves primarily to give strength to the tree trunk. As



FIGURE 2.—Cross section of a log showing annual growth rings. Each light ring is spring wood. Each dark ring is summer wood.

a tree grows in diameter, the inner sapwood changes to heartwood, the change consisting principally in the living cells becoming inactive and the deposit of small amounts of additional materials, usually colored, in the cell cavities and the cell walls. In certain species the portion of such infiltrated material that can be extracted with ordinary solvents is from 5 to 15 percent of the dry weight of the wood, but in most species it is less. In some species, such as the ashes, hickories, and certain oaks, the pores become plugged to greater or less degree with ingrowths, known as tyloses, before the change from sapwood to heartwood takes place. Sapwood should

not be considered as immature or unripe wood but rather as mature living wood, in contrast with the physiologically inactive heartwood.

Sapwood varies greatly in width in different species of trees and even in the same species, the width within a species depending on the vigor and the age of the tree. It is rarely more than 1½ inches thick in most of the cedars, Douglas fir, the spruces, chestnut, and black walnut but frequently is more than 3 inches thick in the maples, hickories, white ash, some of the southern yellow pines, and ponderosa pine.

Although the heartwood is usually darker in color than the sapwood, there is little or no difference between them in color in the spruces (except Sitka spruce), hemlock, the true or balsam firs, Port Orford cedar, basswood, cottonwood, and buckeye. Such species, however, cannot be said to have no heartwood, since other differences in the properties, such as durability and penetrability of liquids, of the inner and outer portions of the tree trunk usually exist (Koehler's Guidebook, and Record).

There is no consistent difference either in the weight when dry or in the strength of sapwood and heartwood. In some trees the sapwood may be heavier and stronger, in others the heartwood, depending on the conditions under which the tree was growing at the time the wood was formed. Wood does not change appreciably in these properties in changing from sapwood to heartwood, except in certain species, such as redwood, western red cedar, and black locust, in which the relatively high percentage of infiltrated material in the heartwood increases the weight and certain strength properties (p. 69).

WOOD CELLS

Wood cells are of various sizes and shapes and are more or less firmly grown together (Brown and Panshin, Forsaith, and Jeffrey). In dry wood the cells are hollow and empty for the most part, although some contain deposits of various sorts. Most of the cells in wood are considerably elongated and pointed at the ends, and for that reason are called fibers. The length of wood fibers varies from about one-twenty-fifth inch in hardwoods to from one-eighth to one-third inch in softwoods. The strength of wood, however, does not depend on the length of the fibers, but rather on the thickness and structure of their walls.

In addition to their fibers, hardwoods have cells of relatively large diameters that comprise the pores, or vessels, through which the sap moves.

In both hardwoods and softwoods strips of cells run at right angles to the fibers, radially in the tree, to conduct sap across the grain. These strips of cells are called rays, wood rays, and medullary rays. In some species of wood the rays are extremely small; in others, such as sycamore and oak, they form the conspicuous flake or silver grain on quarter-sawed surfaces.

Other cells, known as wood parenchyma cells, store food; they occupy a relatively small volume in most woods. In the softwoods there are no special vessels for conducting sap longitudinally in the tree. The wood fibers, which technically are called tracheids, serve this function.

HARDWOODS AND SOFTWOODS

Native species of trees are divided into two classes—hardwoods, which have broad leaves, and softwoods or conifers, which have leaves like needles or scales.

No definite degree of hardness divides the hardwoods and the softwoods. In fact, many hardwoods are actually softer than the average softwood. Softwoods are frequently called conifers, or coniferous woods, because virtually all the native species of softwoods bear cones (Koehler's Guidebook, and Record).

CHEMICAL COMPOSITION OF WOOD

Wood is composed of about 60 percent cellulose, 28 percent lignin, and minor quantities of other materials. Cellulose is a colorless material insoluble in ordinary solvents, such as water, alcohol, and benzine, and in dilute acids and alkalies. It forms the framework of the cell wall.

Lignin is also insoluble in most ordinary solvents but more or less soluble in dilute alkalies. It constitutes the cementing material that binds the cells together and is mixed with cellulose in the cell walls. By dissolving the lignin with suitable reagents the cells may be separated, as in chemical paper-making processes.

Cellulose and lignin are responsible for many of the general properties of wood, such as its hygroscopicity, resistance to corrosion by salt water and dilute acids, and susceptibility to decay. These two major constituents are found in about the same proportions in all species, but in addition there are small quantities of other materials in wood, some of which give certain species or groups of species clearly distinctive characteristics. Color, odor, and natural resistance to decay, for example, come from materials other than cellulose or lignin (Hawley and Wise, and Schorger).

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CHARACTERISTICS OF SOME IMPORTANT COMMERCIAL WOODS

The commercial forest lands of the United States in 1933 included about 495 million acres. Some 190 million acres of these forest lands are saw-timber areas, which are about equally divided between virgin and second growth; 120 million acres are cordwood areas; 102 million acres are of fair to satisfactory restocking areas; and 83 million acres are poor to nonrestocking areas. More detailed data on the commercial forest areas of the United States by character of growth and region are given in table 1 and figure 3.

There are about 180 different species of trees in the United States that may be ranked as commercially important, although only a relatively few species of wood are ordinarily readily available, except in the larger cities (p. 90).

TABLE 1.—*Commercial forest area of the United States, by character of growth and region, 1933*

Region	Total		Saw-timber areas			Cordwood areas	Fair to satisfactory restocking areas	Poor to nonrestocking areas
			Total	Old growth	Second growth			
	Thousand acres	*Percent*	*Thousand acres*	*Thousand acres*	*Thousand acres*	*Thousand acres*	*Thousand acres*	*Thousand acres*
New England	27,273	6	13,860	7,976	5,884	4,843	6,145	2,425
Middle Atlantic	27,139	5	7,294	26	7,268	10,518	5,998	3,329
Lake	55,895	11	5,095	2,664	2,431	8,880	28,165	13,755
Central	64,249	13	21,224	1,664	19,560	25,592	12,245	5,188
South	190,758	39	57,265	14,338	42,927	52,702	37,236	43,555
Pacific coast	66,685	13	44,140	38,892	5,248	6,683	6,190	9,672
North Rocky Mountain	32,329	7	17,026	15,172	1,854	5,704	5,933	3,666
South Rocky Mountain	30,570	6	22,741	18,123	4,618	5,959	161	1,709
Total	494,898	100	188,645	98,855	89,790	120,881	102,073	83,299

The following brief discussion of the principal localities of growth, characteristics, and uses of important commercial species [3] will aid in selecting woods for specific purposes. More detailed information on the properties of these and other species are given in various tables throughout this handbook.

ALDER, RED

Red alder (*Alnus rubra*) grows along the Pacific coast from Washington to southern California but reaches its best development in Washington and Oregon. Although the wood is of comparatively little importance outside its region of growth, yet it is the leading hardwood of the Pacific Northwest. Its importance locally is due both to the intrinsic qualities of the wood and to the scant supply of other commercial hardwoods throughout its range.

The color of red alder varies from almost white to pale pinkish brown. The pores are comparatively small, are fairly uniform in

[3] For further information, the references at the end of this section should be consulted.

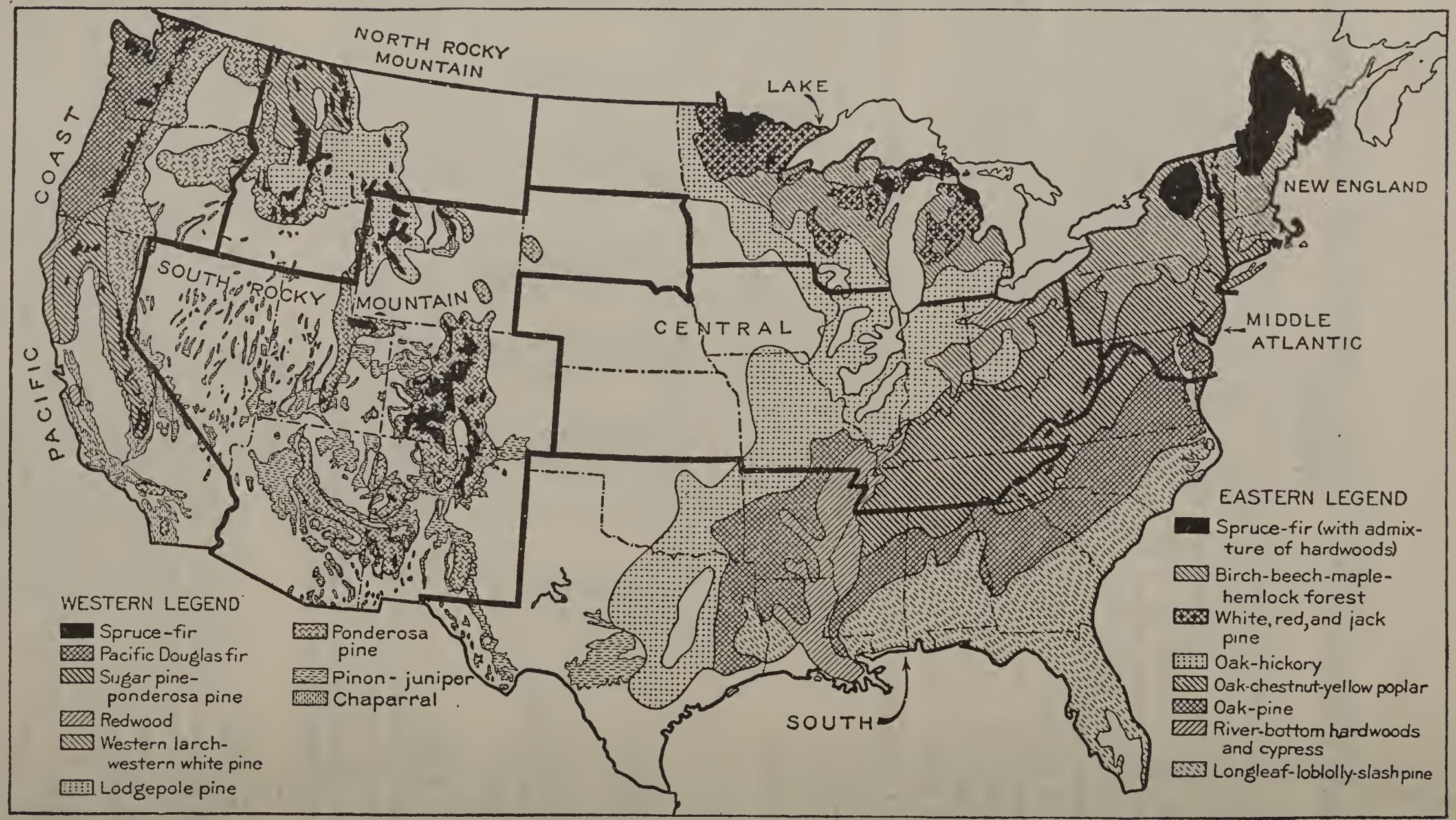


FIGURE 3.—Forest regions and principal types of forest.

size, and rather uniformly distributed. The wood is moderately light, rather weak, does not rate high in shock-resisting ability, is moderately stiff, and shrinks but little. Its chief use is for furniture and chairs.

ASH

The white (*Fraxinus americana*), green (*F. pennsylvania lanceolata*), and black (*F. nigra*) are the important ashes of the 18 species native to the United States. White ash lumber comes principally from New England and the Middle Atlantic and Central States, green ash from the South Atlantic States and the Mississippi Valley, and black ash from the Lake States. Oregon ash (*F. oregona*) occupies a rather narrow strip, 1,000 miles long, extending from Puget Sound to southern California, but is not of commercial importance over half this range. Its best development is in southwestern Oregon.

Commercial white ash, composed primarily of white and green ash, ranks high in weight, strength, hardness, and shock resistance, retains its shape, and wears well. This combination of properties makes the wood especially desirable for such uses as handles, vehicle parts, and agricultural implements. Second-growth commercial white ash, which is usually of more rapid growth and tougher than old-growth ash, is superior for such use. Material from the swelled butts of swamp-growth trees, however, is frequently low in weight, shock resistance, and stiffness.

Black ash is somewhat lower in weight and strength than are white or green ash and hence is used more where other properties, such as workability, cleavage qualities, and capacity to take a finish, are important. It is used extensively for refrigerators, furniture, and boxes and crates.

The strength properties of Oregon ash rank between those of commercial white ash and black ash. The supply is not abundant and its use is largely local. It is used mostly for vehicles, furniture, tool handles, and interior finish.

ASPEN

Aspen (*Populus tremuloides*) grows throughout the Northeast, in the Lake States, in the Rocky Mountains, and in the Northwest. It is one of the most widely distributed trees in the United States.

The wood is soft, weak, moderately light in weight, uniform in texture, and easily worked; it seasons rapidly although subject to warping and checking, and decays rapidly under damp conditions. The broad sapwood is creamy white and the heartwood light brown.

The principal market for aspen logs is for pulp, although the species is also used for lumber, cooperage, excelsior, and matches. Aspen lumber is made largely into small boxes for shipping foods, for which its freedom from taste or odor and its light weight and color make it highly suitable. Some aspen lumber includes balm-of-Gilead (*Populus balsamifera*). The balm-of-Gilead pieces do not have the freedom from taste and odor that makes aspen suitable for food containers.

BASSWOOD

Basswood (*Tilia glabra*) is distributed over the eastern half of the United States, the greater portion coming from the Great Lakes region.

Basswood is light in weight, low in strength, soft in texture, easily workable, and straight grained. The heartwood is creamy brown, and the sapwood creamy white, changing more or less gradually into the heartwood. The sapwood, especially when of rapid growth, has a clean look that, with its other qualities, makes it particularly desirable for boxes, fruit baskets, and woodenware. Other important uses are for furniture and millwork.

BEECH

Beech (*Fagus grandifolia*) grows throughout the eastern part of the United States, excepting some sections in Florida. Pennsylvania, New York, Michigan, Indiana, Ohio, and West Virginia produce the bulk of the beech lumber.

The wood of beech is heavy, strong, hard, and of uniform texture, does not impart a taste or odor to food, and resists abrasion. It is low in resistance to decay. Beech is used considerably for flooring, chairs and other furniture, handles, woodenware, and laundry appliances. It is also highly suitable for food containers and when treated is used for railway ties.

BIRCH

Between 15 and 20 species of birch grow in the United States. Of these yellow birch (*Betula lutea*) is by far the most abundant and most important commercially. Sweet birch (*B. lenta*) ranks next, followed by paper birch (*B. papyrifera*). Yellow birch, sweet birch, and paper birch grow principally in northeastern part of the United States, in the Lake States, and in the Appalachian Mountains. Yellow and sweet birch are cut and sold without distinction simply as birch.

Yellow birch has white sapwood and light reddish brown heartwood. Sweet birch has light-brown sapwood and dark-brown heartwood tinged with red. The wood of both yellow birch and sweet birch is heavy, hard, stiff, and strong and has good shock-resisting ability. It is low in natural resistance to decay. The wood is fine and uniform in texture and is capable of taking a beautiful natural finish. Interior finish and furniture take a large part of the birch cut. Because of its hard and uniformly dense surface, it is well adapted as a base for enamel coating. Other uses are flooring, musical instruments, treated railway ties, and woodenware.

Paper birch is also fine and uniform in texture. The trees are largely white sapwood without figure. The wood is moderately heavy and considerably below yellow and sweet birch in strength and stiffness. Paper birch is used largely for turned products, principally spools, novelties, and toys, and also for toothpicks and shoe pegs.

CEDAR, ALASKA

Alaska cedar (*Chamaecyparis nootkatensis*) grows in the Pacific coast region of North America from southwestern Alaska to northern Oregon. In Washington and Oregon it is usually confined to the western side of the Cascade Mountains.

The wood is of a fine uniform texture and has very small shrinkage. It is moderately light and moderately low in strength. It has excellent working and finishing properties and ranks high in resistance to decay. The heartwood is a bright, clear yellow, and the thin, scarcely distinguishable sapwood is a shade lighter. A large part of the cut is used locally for interior finish, furniture, small boat hulls, cabinet work, and novelties.

CEDAR, PORT ORFORD

Port Orford cedar (*Chamaecyparis lawsoniana*) grows naturally only in a narrow belt bordering the coast of southern Oregon and northern California. The heartwood, which is highly resistant to decay, is light yellow to pale brown in color, and the usually thin sapwood is of similar appearance. The wood is moderately light in weight, of moderate strength and hardness, is of a fine and unusually uniform texture, and has a spicy odor.

The wood is used for battery separators, venetian blinds, boats, interior finish, siding, and shingles. The lower grades are consumed in dock plank, ties, mine timbers, and general construction purposes.

CEDAR, WESTERN RED

Western red cedar (*Thuja plicata*) is an important tree in the humid regions along the North Pacific coast and extends inland from Washington to Montana. The heartwood is reddish brown, and the narrow sapwood is white. The wood is light in weight, easily worked, rather soft and weak, has very little shrinkage, and the heartwood is highly resistant to decay. Western red cedar is a valuable wood for shingles, siding, porch columns, and greenhouse construction, where durability and ease of working are important factors. It holds paint well. Large quantities are used for poles and posts. It is not used extensively for piling, since the wood is likely to crush under heavy driving.

CEDAR, WHITE

The term "white cedar" includes two species, northern white (*Thuja occidentalis*) and southern white cedar (*Chamaecyparis thyoides*). Northern white cedar grows in the Lake States and in the northeastern part of the United States. Southern white cedar grows in the eastern part of the United States, near the coast. Both woods are very light in weight, of low shrinkage, and are soft, brittle, and weak. They split readily, have a characteristic aromatic odor, and their texture is fine and uniform. The heartwood, which is resistant to decay, is light brown with a reddish tinge. The sapwood is lighter in color than the heartwood, sometimes nearly white.

Northern white cedar, which is a relatively small tree, is used principally for posts, ties, poles, and shingles. It is especially desirable for service in contact with the ground. The small quantity of lumber that is manufactured is used principally in small-boat construction.

Southern white cedar, which is a medium-sized tree, is used for shingles, lumber, woodenware, posts, and poles. The lumber, which contains many knots, is made into siding, porch lumber, tanks, and boxes.

CHERRY, BLACK

Black cherry (*Prunus serotina*) grows from Maine to eastern North Dakota and southward to central Florida and central Texas. It is, however, scattered sparsely throughout the forests. The scattered distribution over a large area insures a fairly steady though limited supply.

The wood of black cherry is strong and moderately hard. It has good shock-resisting ability, a moderate degree of stiffness, and a very moderate shrinkage. The heartwood varies in color from light to dark reddish brown and has a beautiful and distinctive luster. The sapwood is narrow and nearly white. The annual rings show on a cross section but are not prominent. The wood has a fairly uniform texture and contains numerous scattered pores. Black cherry stays in place well after seasoning. It is exceptionally well suited for engraver's block and is also desirable for paneling and furniture.

CHESTNUT

Chestnut (*Castanea dentata*), which has long been one of our important commercial woods, has many uses. The blight that is now exterminating chestnut is only a bark disease, so that virtually all the wood of blight-killed chestnut trees is entirely satisfactory for lumber if the trees are cut and utilized before checking, insect attack, or decay begins. The principal commercial range of this species was in southern New England and the Appalachian Mountains. Most of the remaining chestnut timber is in the southern Appalachians.

Chestnut is moderately low in weight and strength, is straight-grained, and stays in place well. The wood has large distinct pores, and the sapwood is narrow. The heartwood, which is grayish brown, is highly resistant to decay. Poles and fence posts are among the important uses for chestnut. Planing-mill products, core stock in veneer panels, caskets and coffins, furniture, and boxes and crates are other extensive uses.

COTTONWOOD

The name cottonwood is applied to 10 or 12 closely related species of trees that grow in the United States, of which eastern cottonwood (*Populus deltoides*) and northern black cottonwood (*P. trichocarpa hastata*) are the most important. Eastern cottonwood is widely distributed east of the Rocky Mountains and black cottonwood in the Northwest.

The wood is light in weight, weak, and has a tendency to warp in seasoning. It is odorless, has unusually uniform texture, works nicely, and does not split easily. The annual growth rings are scarcely noticeable. It decays quickly when in contact with the ground.

More than one-half of the cottonwood lumber is used in boxes and crates. Other uses include vehicle parts, planing-mill products, agricultural implements, woodenware, laundry appliances, and trunks. In addition to the lumber cut, large amounts of cottonwood are cut into veneer.

CYPRESS, SOUTHERN

Southern cypress (*Taxodium distichum*) is found in the low swamp lands along the southeastern coast of the United States and as far up the Mississippi River Valley as Missouri. When grown in swamps near salt water, lumber from this species is called, by the trade, red cypress or tidewater red cypress, and the inland or upland growth is called yellow or white cypress. The heartwood from cypress near salt water will vary in color from slightly reddish to almost black, while that found farther inland is only slightly reddish or yellowish brown.

Southern cypress is moderately light and moderately strong, and the heartwood is highly decay-resistant. The wood is largely used where decay is an important factor. It holds paint well. Doors, sash, porch material, siding, tanks, and greenhouse construction are among the important uses for southern cypress.

DOUGLAS FIR

The properties of Douglas fir (*Pseudotsuga taxifolia*) are affected by the location of the stand. The strongest wood of this species grows in the coastal region of Washington, Oregon, and California, the intermediate class grows in the "Inland Empire"[4] and the mountains of California, and the least strong grows in the Rocky Mountains. Douglas fir from the "Inland Empire" is often sold as larch and fir; that from the Rocky Mountains is often sold as red fir. Most of the lumber sold as Douglas fir comes from the coast region.

Some Douglas fir trees in the coast region are very large—up to 8 feet in diameter breast high. On rare occasions trees up to 14 feet are found. The quality of the wood in different portions of these trees varies greatly. Lumber from the top of the tree usually has more knots and is less dense than the butt cut. Lumber from the center of the average log, which is usually of more rapid growth than the rest of the tree, is consumed mostly in light construction although some boxed-heart timbers of large size and ties are cut from such logs. The strongest structural timbers from these large logs are sawed farther from the center, where the wood is of slower growth. Nearer the bark the wood is frequently of still slower growth; it is softer, more uniform in texture, and the outer heartwood is more yellowish in color. This wood is used for interior and exterior trim, flooring, doors, long ladder rails, and similar products.

Douglas fir in the form of lumber and timbers is one of the most desirable native woods for structural purposes, and it also has extensive use as poles, piling, and ties. For structural material of highest quality the density rule for this species should be included. Large quantities are cut into veneer for plywood and other purposes. It is strong, moderately hard and heavy, and the heartwood is moderately durable. In general, it has a tendency to check and split and does not hold paint well. although its paint reten-

[4] Northwestern Montana, Idaho north of Salmon River, Washington east of the Cascade Mountains, and northeastern tip of Oregon.

tion can be materially improved by methods suggested on pages 230 and 239. All virgin Douglas fir has little sapwood.

The existing stand of merchantable Douglas fir is larger than that of any other species.

ELM

The three species constituting the greater part of the elm lumber produced in the United States are American (*Ulmus americana*), slippery (*U. fulva*), and rock elm (*U. racemosa*). The growth range of American and slippery elm (sold as commercial soft elm) includes most of the area east of the Rocky Mountains. Rock elm is confined largely to the North Central States. The principal supply of these three species comes from the Lake States and the Mississippi Valley.

Rock elm is heavy, hard, and strong and has a high capacity to resist shock. It is valuable for its strength and bending qualities. Soft elm is lighter and has lower strength properties than rock elm, although very dense pieces have sufficient strength to be used with rock elm. Elm in general is used to a large extent for slack cooperage, some vehicle parts, and boxes and crates.

FIR, BALSAM

Balsam fir (*Abies balsamea*) grows principally in New England, southward to Pennsylvania, and in the Lake States. The wood is nearly white and has little figure. It is light in weight, soft and low in strength. Much of it is used in rough form for buildings.

FIR, WHITE

White fir (*Abies concolor*) and lowland white fir (*A. grandis*) are both known commercially as white fir. Lowland white fir is cut mainly in Idaho and in California near the coast, and true white fir in the mountain region of California.

Commercial white fir is light in weight and moderately low in strength, moderately soft, straight grained, of medium and fairly uniform texture, nonresinous, and easily worked. Its resistance to decay is low. The heartwood is white with a reddish tinge, and the sapwood is not distinguishable from the heartwood. It has less color than any other commercial softwood.

The chief consumption of this wood is in the construction of small houses, largely as dimension and common boards. Other uses are for general millwork, planing-mill products, and boxes.

GUM, RED AND SAP

Red gum (*Liquidambar styraciflua*) is a native of the swamp and bottom lands in the South that are dry for the greater part of the year.

Although its tendency to warp badly in seasoning long kept it out of commercial use, research ultimately found the proper methods of drying and handling, and in consequence red gum lumber, as produced by responsible manufacturers, has for years been a satisfactory

commercial material. The color of the heartwood, which is sold as red gum, ranges from a light to a deep reddish brown. The sapwood, which is commercially called sap gum and looked upon as a distinct kind of lumber, is nearly white. The wood is moderately heavy and strong, of fine, uniform texture, and will take a beautiful finish. The heartwood is moderately durable. Red gum is used both in lumber and veneered form for finish and furniture. The lower grades are used for boxes and crates.

HACKBERRY

The range of hackberry (*Celtis occidentalis*) extends from New England to Virginia and westward to eastern North Dakota, Iowa, southwestern Missouri, and western Kansas. Sugarberry (*C. laevigata*) occurs from the coast of Virginia to southern Florida, and westward through the Gulf States to the valley of the Rio Grande and to eastern Texas, Arkansas, eastern Oklahoma, Missouri, eastern Kansas, southern Illinois, Indiana, Kentucky, and Tennessee. Both sugarberry and hackberry species are marketed as hackberry, though hackberry represents the far greater percentage of the lumber cut. Both species occur in stands associated with elm, walnut, hickory, ash, and other hardwood species. Although hackberry is widely distributed, its commercial range is chiefly the river bottoms and creek valleys of the Middle West.

The annual reported cut is not large, but this is only a part of the total output, since it is often sold with the lower grades and for the less exacting uses of ash and also sometimes sold with elm. In color it is more yellowish than ash, but the annual rings of growth resemble that wood. The wood is moderately heavy, rather weak as a beam, is limber, good in shock resistance, and moderately hard.

It is used mostly for furniture and vehicles. Some is used for refrigerators and kitchen cabinets, baskets, boxes, and crates.

HEMLOCK, EASTERN

Eastern hemlock (*Tsuga canadensis*) grows principally in the Lake States and in the mountains in the eastern part of the United States. The wood is pale buff in color with a reddish tinge, is moderately light in weight, and moderately low in strength. It has a tendency to splinter, is subject to ring shake, and is not decay-resistant. The lumber is nonresinous, holds nails well, and the knots are characteristically small. Eastern hemlock is used largely for framing, sheathing, roofing, and subflooring. In the nominal 2-inch size the stock is cut extra thick, thus partly equalizing the greater strength of some other structural woods. Eastern hemlock lumber is carefully manufactured and graded and consequently can be purchased in quality well suited for general building.

A small amount of tamarack (*Larix laricina*), a species heavier and stronger than eastern hemlock, is sawed into lumber and is often sold with eastern hemlock. Most tamarack, however, is utilized in the form of poles, posts, ties, and mine props, reaching the market under its own name.

HEMLOCK, WESTERN

Large stands of western hemlock (*Tsuga heterophylla*) extend along the Pacific coast from Alaska to northern California, penetrating farther inland just below the Canadian boundary than elsewhere. This species, which is sold commercially as west coast hemlock, is distinct from eastern hemlock.

Western hemlock is a uniform fine-textured wood and is comparatively free of ring shakes. It is moderately light in weight, moderately high in strength properties, usually is straight grained, and is nonresinous; its many small black knots are ordinarily fixed firmly in place. Its resistance to decay is low. Western hemlock in the common grades is mixed and sold with Douglas fir.

Western hemlock is used largely in house construction for framing, sheathing, and subfloors. Large quantities go also into siding, ceiling, flooring, and shiplap. Other uses are sash, doors, blinds, general millwork, and crossties.

HICKORY, PECAN

Pecan hickory includes bitternut (*Hicoria cordiformis*), nutmeg (*H. myristicaeformis*), pecan (*H. pecan*), and water hickory (*H. aquatica*) and is found throughout much of the eastern half of the United States. Although these hickories rank relatively high in strength properties, the true hickories are somewhat superior, especially in shock resistance. Pecan is used for the same purposes as the true hickories, namely, for vehicle parts, tool and implement handles, and special products such as the shafts of golf clubs, ladder rungs, doweling, and gymnasium apparatus. The bulk of the hickory consumed for these purposes, however, is true hickory.

Like the true hickories, pecan is commonly classified as white, which is the sapwood, or red, which is the heartwood. As with the other hickories, color is no criterion of its strength.

HICKORY, TRUE

The true hickories are found throughout most of the eastern half of the United States and are all similar in their properties. The species most important commercially are bigleaf shagbark (*H. laciniosa*), mockernut (*H. alba*), pignut (*H. glabra*), and shagbark (*H. ovata*).

Hickory is commonly classified as white, which is the sapwood, and red, which is the heartwood. Color, however, is no criterion of its strength because weight for weight, sound hickory has the same strength and toughness regardless of whether it is red, white, or mixed red and white.

True hickory is very tough, heavy, hard, and strong; the combination of high strength, stiffness, hardness, and shock resistance has not been found in any other native commercial wood. It is low in natural decay resistance and shrinks considerably in drying. Hickory having not more than 20 rings to the inch is generally the strongest, although slow-growth hickory, if heavy, also has high strength

properties. Occasionally fast-growing hickory from the butt, sometimes known in the trade as "rubber hickory", is very deficient in stiffness, although it usually is comparatively heavy. When in pieces of small cross section, such as blanks for golf shafts, rubber hickory can usually be culled by means of the dull tone it emits when dropped endwise on a hard surface; stiff hickory gives a clear, ringing tone under this test.

True hickory, which is one of the prominent specialty woods, is used principally in the vehicle industry for spokes, rims, poles, and shafts, in the tool-handle industry for ax, pick, sledge, and hatchet handles, and for special products, such as golf-club shafts, ladder rungs, doweling, and gymnasium apparatus.

LARCH, WESTERN

Western larch (*Larix occidentalis*) is native principally to the "Inland Empire." The heartwood is reddish brown, and the sapwood, which usually is not more than 1 inch thick, is yellowish white. In its natural color the wood finishes well, but it does not hold paint well. The wood splits easily and is subject to ring shakes. Knots, although common, are usually small. Its resistance to decay is moderate. It is rated as moderately heavy, strong, stiff, and moderately good in shock resistance. Western larch and Douglas fir are logged together and are frequently manufactured, graded, and sold together as larch-fir.

Western larch is used largely in building construction as rough dimension, small timbers, planks, and boards. Planing-mill products, sash, doors, boxes, and crates take a small portion of it. It is a satisfactory wood for rough construction, and its use as an interior trim is increasing because of its pleasing appearance and ease of finishing.

LOCUST, BLACK

The principal range of black locust (*Robinia pseudoacacia*) is in the Appalachian Mountains from Pennsylvania to northern Georgia. The natural range also includes the southern part of Illinois and Indiana, and part of Arkansas, Oklahoma, and Tennessee.

Black locust is one of the heaviest and hardest native woods. It ranks very high in shock-resisting ability and strength. It has a moderately small shrinkage which for its density is very low. The heartwood is very durable. Black locust is subject to wormholes, cross grain, and bird pecks. Checking and splitting generally occur to only a moderate degree. Its principal uses are for insulator pins, treenails, wagon hubs, fence posts, mine timbers, and poles.

MAGNOLIA

Evergreen magnolia (*Magnolia grandiflora*) grows along the coast from North Carolina to Florida and westward in the Gulf coast region to Texas and through western Louisiana to southern Arkansas. The range of cucumber magnolia (*M. acuminata*) extends from western New York to Alabama following the Appalachian Mountains and westward to Illinois and Mississippi, ap-

pearing west of the Mississippi River in Arkansas. It is of the largest size and is the most abundant in the narrow valleys in eastern Tennessee and the western parts of the Carolinas.

The wood of the evergreen and cucumber magnolias resembles that of yellow poplar, but it usually is somewhat harder and heavier and often has a light to dark purplish color.

A large part of cucumber magnolia and some of the evergreen magnolia lumber are marketed with the lower grades of yellow poplar. During the years immediately preceding the economic depression, an average of about 27 million feet of evergreen magnolia was marketed annually as magnolia, and about one-half million feet of cucumber magnolia was marketed as cucumber. Important uses of these woods include furniture, planing-mill products, finish, siding, and boxes and crates.

MAPLE

Of the 13 species of maple that grow in the United States, sugar maple (*Acer saccharum*) and black maple (*A. nigrum*), jointly classed as hard maple, are by far the most important as well as the most abundant. Others of commercial importance are silver (*A. saccharinum*) and red (*A. rubrum*), which are commonly called soft maple, and bigleaf or Oregon maple (*A. macrophyllum*), which belongs in the soft-maple group on the basis of its properties. The commercial maples, as a group, grow throughout the eastern part of the United States, with the exception of bigleaf maple, which appears on the Pacific coast. Hard maple, which has a wide range, is found principally in the Lake States, the Northeast, and in the Appalachians.

The heartwood of hard maple is light reddish brown and its sapwood white with a slight reddish brown tinge. The white maple of commerce is the unstained sapwood of sugar maple. The wood of this species is heavy, hard, strong, and stiff, has good resistance to shock, and wears well under abrasion, excelling the other maples in these properties. It has moderate shrinkage and uniform texture. The grain is usually straight but sometimes curly, wavy, or birdseye grain occurs.

Both silver maple and red maple are lighter in color and not so heavy, hard, or strong as sugar maple. Silver maple is lighter in weight and weaker than red maple. The strength properties of bigleaf maple are intermediate between silver and red maple.

Maple is used for flooring and other planing-mill products, interior trim, and furniture. Large quantities also go into agricultural implements, handles, and vehicle parts.

OAK

All the oaks of commercial importance, about 15 of the 60 or more native species, grow in the eastern half of the United States, especially in the Mississippi Valley and the South. In the lumber trade the oaks are commonly divided into two groups, red oak and white oak, and no attempt at a finer distinction is made in most cases.

The common and botanical names of commercial white oak are: White oak (*Quercus alba*), chestnut oak (*Q. montana*), swamp chestnut oak (*Q. prinus*), swamp white oak (*Q. bicolor*), post oak (*Q. stellata*), overcup oak (*Q. lyrata*), and bur oak (*Q macrocarpa*).

The common and botanical names of commercial red oak are: Red oak (*Quercus borealis*), swamp red oak (*Q. rubra pagodaefolia*), southern red oak (*Q. rubra*), pin oak (*Q. palustris*), black oak (*Q. velutina*), water oak (*Q. nigra*), and willow oak (*Q. phellos*).

White oak heartwood is more durable and of lighter color than red oak. Furthermore, the pores in the heartwood of white oak are for the most part plugged with a growth called tyloses, which makes the wood much less permeable to liquids than that of red oak. Oak is commonly sold both plain and quarter-sawed with advantages in each, among which are more pronounced figure in plain-sawed material and less shrinkage in quarter-sawed material.

Oak is heavy, hard, stiff, and strong. Although there is no important difference between red and white oak in these properties, the oaks like all other species vary in their properties within a single species. Rapidly grown oak is generally stronger, harder, and tougher than slow-growth oak, which is finer grained, softer, and more easily worked.

Flooring, interior trim, furniture, motor-vehicle parts, and implements consume a large part of the oak cut, and in addition oak is used for cooperage, piling, crossties, and timbers.

PINE, LODGEPOLE

Lodgepole pine (*Pinus contorta*) is widely distributed throughout the western part of the United States. The wood is light in color with the heartwood only slightly darker than the sapwood. It is one of the lightest in weight of the yellow pines, is moderately low in strength, and small knots are characteristic. Lodgepole pine is not durable in contact with the ground, but the sapwood accepts preservative treatment readily. In mature stands only about 20 percent of the material is large enough for saw timber; much of the cut is used for poles, mine props, and ties.

PINE, NORTHERN WHITE

Northern white pine (*Pinus strobus*), originally known just as "white pine", is found principally in the Lake States, the Northeastern States, and the Appalachian region. The sapwood is white, and the heartwood ranges from cream to light reddish brown. The wood is moderately light in weight, moderately low in strength, and usually straight grained. The soft, uniform texture of the virgin growth has won for it extensive use in building and millwork. Changing dimension little with changes in moisture content and easily worked, the species makes a desirable wood for patterns. The second-growth pine is usually of faster growth, and more knotty than old growth. Second growth and the lower grades of virgin-growth pine are largely used for boxes and crates. Virgin growth is becoming scarce.

Norway pine (*Pinus resinosa*) of the Lake States, although belonging to the yellow pine group, is sold with northern white pine in the lower common grades. It is somewhat coarser in grain and texture, however, has more strongly marked annual rings, is heavier and stronger, and is somewhat more resinous.

PINE, PONDEROSA

Ponderosa pine (*Pinus ponderosa*) grows from Washington to the Black Hills and southward in the Rocky Mountain and Pacific coast regions.

The wood is moderately light in weight, moderately low in strength, and ranks relatively low in shrinkage. It is easy to work, stays in place well, and has a uniform texture, being somewhat comparable in these respects with the white pines.

The principal uses of ponderosa pine are for sash and frames, doors, general millwork, building construction, and boxes and crates. Considerable quantities are treated and used for railway ties.

PINE, SOUTHERN YELLOW

Commercial southern yellow pine, in one species or another grows in the Atlantic and Gulf States from New Jersey to Texas and as far north as Pennsylvania, West Virginia, Kentucky, and Missouri. Although a large part of the original stand has been cut, the amount remaining, the rapidity of growth, and the ease of reproduction assure an adequate supply for many years, if not indefinitely.

Southern yellow pine is a general name for a number of closely related species, chiefly longleaf (*Pinus palustris*), shortleaf (*P. echinata*), loblolly (*P. taeda*), slash (*P. caribaea*), and pond pine (*P. rigida serotina*). Except for the fact that the pith often distinguishes longleaf from loblolly, shortleaf, and slash pines, the species cannot be positively distinguished by the wood alone.

The 1932 grading rules of the Southern Pine Association classify all their "structural" material as either longleaf or shortleaf. As there defined, longleaf yellow pine structural timbers must be manufactured from original-growth longleaf (*Pinus palustris*) trees, must show not less than six annual rings per inch, and must contain not less than one-third summer wood (measured according to the density rule as adopted by the American Society for Testing Materials on Aug. 21, 1915). Similarly, all shortleaf yellow pine structural timbers must meet the density requirement, but differ from longleaf in that material with less than six rings per inch, provided it contains 50 percent summer wood, may also be included. As the association interprets its rules, shortleaf yellow pine structural timbers do not necessarily have to be manufactured from shortleaf (*P. echinata*) trees; that is, they may be manufactured from any of the several southern yellow pine species, provided the material is dense.

Both longleaf and shortleaf structural timbers, as defined by the Southern Pine Association, are highly desirable for structural purposes. The wood is dense, moderately hard, strong, and the heartwood is moderately durable.

Southern yellow pine lumber of low density, although lacking the strength of dense stock, is more desirable for some purposes, such as interior trim. It checks less than the dense stock, is more easily worked, splits less in nailing, often holds a coating of finish better, is superior in thermal insulation, and because of lighter weight may be handled and shipped at lower cost. Large uses for the low-density stock are in light buildings, temporary construction, millwork, boxes and crates. Southern yellow pine is an excellent general utility wood. In general, it has a tendency to check and split; and it does not hold paint well, although its paint retention can be materially improved by methods suggested on pages 230 and 239.

The wide-ringed, lightweight, easily worked, and soft southern yellow pine lumber of comparatively low strength that is grown in the Atlantic Coastal Plain is largely loblolly and is known as North Carolina pine, and the soft, easily worked pine of uniform texture and low strength, produced chiefly from shortleaf stands in or near the Ozark Mountains, is called Arkansas soft pine.

The sapwood of all the southern pines is easily treated for preservation, and pieces containing a large proportion of sapwood are readily obtained.

PINE, SUGAR

Sugar pine (*Pinus lambertiana*) is native to California and southern Oregon. It is similar in appearance and properties to northern white pine, but can usually be distinguished by its more conspicuous resin ducts. Sugar pine is the largest of the species of the white pine group, and the bulk of the exceptionally wide, thick stock of soft pine lumber is cut from this species. A large part goes into the manufacture of planing-mill products, such as sash, blinds, and drain boards, and into millwork. It is used interchangeably with northern white and western white pine for many purposes.

PINE, WESTERN WHITE

Western white pine (*Pinus monticola*), sold commercially as Idaho white pine or Idaho pine, grows principally in northern Idaho, eastern Washington, and western Montana. Western white pine resembles northern white pine so closely that the clear wood of the two is indistinguishable. Patternmakers state that western white pine is somewhat more difficult to work, although both are regarded highly for their workability.

Western white pine is light in color, moderately light in weight, and straight grained. It swells and shrinks a little more with changes in moisture content, but on the whole compares favorably with northern white pine and is largely used for the same purposes as northern white pine.

POPLAR, YELLOW

Yellow poplar (*Liriodendron tulipifera*) is one of the largest native trees supplying lumber; under favorable conditions it reaches a diameter of 6 to 8 feet and a height of 100 to 160 feet. It grows throughout the eastern part of the United States, with the largest stands in the southern Appalachian Mountains. The sapwood, fre-

quently several inches in thickness, is white. The heartwood is yellowish brown with a greenish tinge. The wood is moderately light in weight, straight grained, moderately soft, moderately weak, comparatively uniform in texture, easy to nail because it does not split readily, easy to glue, stays in place well, holds paint and enamel well, is easily worked, and finishes smoothly.

Yellow poplar is especially suitable for finish, siding, furniture, and other products that are to be painted or enameled. It is largely used for planing-mill products, furniture, veneer, and panels. The lower grades are used for boxes and crates. Other less important uses are vehicle parts, musical instruments, and car construction.

Cucumber magnolia (*Magnolia acuminata*) and evergreen magnolia (*M. grandiflora*) are sometimes sold with the lower grades of yellow poplar, though they can be purchased under their own names. The wood of these species resembles that of yellow poplar, but it usually is somewhat harder and heavier and often has a light to dark purplish color.

REDWOOD

The commercially important stands of redwood (*Sequoia sempervirens*) are chiefly confined to a narrow belt, 10 to 30 miles wide, that extends from southern Oregon to within a few miles of San Francisco. The redwood forest in a small area south of San Francisco is also of commercial importance.

The heartwood of redwood varies in color from cherry to dark mahogany, and the sapwood, which is very narrow, is almost white. Many of the redwoods are extremely large, individual trees commonly reaching diameters of 5 to 10 feet. Exceptional trees attain a diameter of 20 feet or more. Such size permits a high percentage of clear lumber, and unusually wide clear boards are easily obtained. Redwood is moderately light in weight and moderately strong. The heartwood is especially valuable where resistance to decay is important because of its high durability. It has a low shrinkage, stays in place well, and is not difficult to work.

Redwood is used for sash, doors, frames, siding, and interior and exterior finish and is valuable also for posts, crossties, tanks, pipes, flumes, greenhouses, and other service in which the structural material is subject to conditions that favor decay. It holds paint well. Redwood is also used as structural timber for highway bridges, trestles, mill roofs, and similar structures.

SPRUCE, EASTERN

The term "eastern spruce" includes three species, red (*Picea rubra*), white (*P. glauca*), and black spruce (*P. mariana*). White spruce and black spruce grow principally in the Lake States and New England, and red spruce in New England and the Appalachian Mountains. All three species have about the same properties, and in commerce no distinction is made between them. The wood dries easily, stays in place well, is moderately light in weight, and easily worked, has a moderate shrinkage and a moderate degree of strength, stiffness, toughness, and hardness. Eastern spruce is not resistant

to decay. The wood is light in color, and there is little difference between the heartwood and sapwood.

Eastern spruce is used principally for framing material and general millwork. Large quantities are also used in boxes and crates.

SPRUCE, SITKA

Sitka spruce (*Picea sitchensis*) grows in a narrow strip, seldom more than 40 miles wide, along the Pacific coast from Alaska to Northern California. The wood is light in weight and has a moderate degree of hardness, stiffness, toughness, and strength. It ranks high in strength for its weight, and on this account and also because it can be obtained in clear, straight-grained pieces of large size and uniform texture Sitka spruce is the favored wood for airplanes. The wood dries easily, stays in place well, has a moderate shrinkage, and is easily worked. It is not resistant to decay.

Sitka spruce is used for sash, doors, siding, ceiling, flooring, exterior and interior finish, and aircraft construction. Large quantities go into boxes, crates, and ladders.

SYCAMORE

Sycamore (*Platanus occidentalis*) grows widely in the eastern half of the United States, but the greater portion comes from the bottom lands along the Mississippi River and its tributaries. Sycamore is moderately heavy and moderately strong. The heartwood is redish brown, and the sapwood is somewhat lighter in color. In quarter-sawed sycamore the rays are conspicuous, but the plain-sawed lumber has little figure. Seasoning the wood without warping is difficult, especially when it is plain-sawed. Sycamore is used principally for interior trim and fancy paneling. Other uses are baskets, boxes and crates, and furniture.

TUPELO AND BLACK GUM

Tupelo gum (*Nyssa aquatica*) is found principally in the swampy regions of the South. Black gum (*N. sylvatica*) is native to all States east of the Mississippi River. In the South it grows as far west as Texas. Tupelo gum and black gum are sold both under their respective names and in mixture as one or the other because there is no way of positively identifying the wood of the two species. These species were not cut for lumber to any great extent until about 25 years ago, at which time better means of handling and utilization were developed.

The lumber of tupelo and black gum is largely sapwood, which is grayish white when dry, soft, of fine texture, moderately heavy, and moderately strong, but is cross-grained, tends to warp, and is difficult to split. It is used largely for boxes and crates, flooring, inside finish, furniture, and vehicle parts. For factory floors, bridge flooring, and platforms subjected to heavy wear it has proved very satisfactory but requires preservative treatment when used under conditions that favor decay.

The wood cut from the true black gum tree is, on the average, harder and stronger than that of the true tupelo gum. Where a pretense

is made commercially of differentiating between black gum and tupelo gum lumber it is usually on the basis that the harder material passes as black gum and the softer as tupelo gum even though actual species lines are disregarded in segregation.

WALNUT, BLACK

Black walnut (*Juglans nigra*), one of the most beautiful native woods, is found in commercial quantities chiefly in Missouri, Iowa, Illinois, Indiana, Ohio, Kentucky, and Tennessee, although it grows to some extent from New England to Texas.

The heartwood, which is brown, varies from light to dark in color. The sapwood is nearly white. The wood is heavy, hard, strong, and stiff. It stays in place well, takes stain and other finishes exceedingly well, and will also take a good polish. Besides this it is easily worked and glues satisfactorily.

Black walnut is used largely for cabinet work, furniture, interior finish, and gun stocks. Figured and the higher grade black walnut is extensively cut into veneer and used as faces in plywood and panel construction.

Butternut is related to walnut botanically and is sometimes actually called white walnut, but the wood is radically different in most respects. Butternut is soft and has low strength properties, but the grain and color are attractive and the wood is used to a limited extent for decorative purposes, particularly in the form of veneer.

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PHYSICAL PROPERTIES OF WOOD

DECORATIVE FEATURES OF COMMON WOODS

The decorative value of wood depends upon its color, figure, luster, and the way in which it takes fillers, stains, fumes, and transparent finishes (Koehler, Identification of Furniture Woods).[5]

Because of the combinations of color and the multiplicity of shades found in wood, it is impossible to give detailed descriptions of the colors of the various kinds. The sapwood of all species, however, is light in color and in some species it is practically white. The white sapwood of certain species, such as maple, makes it preferable to the heartwood for specific uses. In some species, such as hemlock, the true firs, basswood, cottonwood, and beech, there is little or no difference in color between sapwood and heartwood, but in most species the heartwood is darker and fairly uniform in color. Table 2 describes in a general way the color of the heartwood of the more common kinds of woods.

TABLE 2.—*Color and figure of common kinds of wood*

Species of wood	Color of heartwood [1]	Type of figure in—	
		Plain-sawed lumber or rotary-cut veneer	Quarter-sawed lumber or quarter-sliced veneer
HARDWOODS			
Alder, red	Pale pinkish brown	Faint growth ring	Scattered large flakes, sometimes entirely absent.
Ash, black	Moderately dark grayish brown.	Conspicuous growth ring; occasional burl.	Distinct, not conspicuous growth-ring stripe; occasional burl.
Ash, Oregon	Grayish brown, sometimes with reddish tinge.	do	Do.
Ash, white	do	do	Do.
Aspen	Light brown	Faint growth ring	None.
Basswood	Creamy white to creamy brown, sometimes reddish.	do	Do.
Beech	White with reddish tinge, to reddish brown.	do	Numerous small flakes up to one-eighth inch in height.
Birch, paper	Light brown	do	None.
Birch, sweet	Dark reddish brown	Distinct, not conspicuous growth ring; occasionally wavy.	Occasionally wavy.
Birch, yellow	Reddish brown	do	Do.
Butternut	Light chestnut brown with occasional reddish tinge or streaks.	Faint growth ring	None.
Cherry, black	Light to dark reddish brown.	Faint growth ring; occasional burl.	Occasional burl.
Chestnut	Grayish brown	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.

[1] The sapwood of all species is light in color or virtually white, unless discolored by fungous or other chemical stains.

[5] For further information, the references at the end of this section should be consulted.

TABLE 2.—*Color and figure of common kinds of wood—Continued*

Species of wood	Color of heartwood	Type of figure in—	
		Plain-sawed lumber or rotary-cut veneer	Quarter-sawed lumber or quarter-sliced veneer
HARDWOODS—con.			
Cottonwood	Grayish white to light grayish brown.	Faint growth ring	None.
Elm, American and rock.	Light grayish brown, usually with reddish tinge.	Distinct, not conspicuous, with fine wavy pattern within each growth ring.	Faint growth-ring stripe.
Elm, slippery	Dark brown with shades of red.	Conspicuous growth ring, with fine pattern within each growth ring.	Distinct, not conspicuous growth-ring stripe.
Gum, black and tupelo.	Pale to moderately dark brownish gray.	Faint growth ring	Distinct, not pronounced ribbon.
Gum, red	Reddish brown	Faint growth ring; occasionally irregular darker streaks in "figured" gum.	Distinct, not pronounced ribbon; occasionally irregular darker streaks in "figured" gum.
Hackberry	Light yellowish or greenish gray.	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.
Hickory	Reddish brown	Distinct, not conspicuous growth ring.	Faint growth-ring stripe.
Honey locust	Cherry red	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.
Locust, black	Golden brown, sometimes with tinge of green.	Conspicuous growth rings	Do.
Magnolia	Light to dark yellowish brown with greenish or purplish tinge.	Faint growth ring	None.
Maple, black, bigleaf, red, silver, and sugar.	Light reddish brown	Faint growth ring; occasionally bird's eye, curly, and wavy.	Occasionally curly and wavy.
Oak, all species of red oak group.	Grayish brown, usually with fleshy tinge.	Conspicuous growth ring	Pronounced flake; distinct, not conspicuous growth-ring stripe.
Oak, all species of white oak group.	Grayish brown, rarely with fleshy tinge.	do	Do.
Poplar, yellow	Light to dark yellowish brown with greenish or purplish tinge.	Faint growth ring	None.
Sugarberry	Light yellowish or greenish gray.	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.
Sycamore	Flesh brown	Faint growth ring	Numerous pronounced flakes up to one-fourth inch in height.
Walnut, black	Chocolate brown occasionally with darker, sometimes purplish streaks.	Distinct, not conspicuous growth ring; occasionally wavy, curly, burl, and other types.	Distinct, not conspicuous growth-ring stripe; occasionally wavy, curly, burl, crotch, and other types.
SOFTWOODS			
Cedar:			
Alaska	Yellow	Faint growth ring	None.
Eastern red	Brick red to deep reddish brown.	Occasionally streaks of white sapwood alternating with heartwood.	Occasionally streaks of white sapwood alternating with heartwood.
Incense	Reddish brown	Faint growth ring	Faint growth-ring stripe.
Northern white	Light to dark brown	do	Do.
Port Orford	Light yellow to pale brown.	do	None.
Western red	Reddish brown	Distinct not conspicuous growth ring.	Faint growth-ring stripe.
White	Light brown with reddish tinge.	do	None.
Cypress, southern	Light yellowish brown to reddish brown.	Conspicuous irregular growth ring.	Distinct, not conspicuous growth-ring stripe.
Douglas fir	Orange-red to red; sometimes yellow.	Conspicuous growth ring	Do.
Fir:			
Balsam	Nearly white	Distinct, not conspicuous growth ring.	Faint growth-ring stripe.
White	Nearly white to pale reddish brown.	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.
Hemlock:			
Eastern	Light reddish brown	Distinct, not conspicuous growth ring.	Faint growth-ring stripe.
Western	do	do	Do.

TABLE 2.—*Color and figure of common kinds of wood—Continued*

Species of wood	Color of heartwood	Type of figure in—	
		Plain-sawed lumber or rotary-cut veneer	Quarter-sawed lumber or quarter-sliced veneer
SOFTWOODS—con.			
Larch, western	Russet to reddish brown	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.
Pine:			
Lodgepole	Light reddish brown	Distinct, not conspicuous growth ring; faint "pocked" appearance.	None.
Northern white	Cream to light reddish brown.	Faint growth ring	Do.
Norway	Orange to reddish brown.	Distinct, not conspicuous growth ring.	Faint growth-ring stripe.
Ponderosa	do	do	Do.
Southern yellow [2]	do	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.
Sugar	Light creamy brown	Faint growth ring	None.
Western white	Cream to light reddish brown.	do	Do.
Redwood	Cherry to deep reddish brown.	Distinct, not conspicuous growth ring occasionally wavy and burl.	Faint growth-ring stripe; occasionally wavy and burl.
Spruce:			
Black, Engelmann, red, white.	Nearly white	Faint growth ring	None.
Sitka	Light reddish brown	Distinct, not conspicuous growth ring.	Faint growth-ring stripe.
Tamarack	Russet brown	Conspicuous growth ring	Distinct, not conspicuous growth-ring stripe.

[2] Includes longleaf, loblolly, shortleaf, and slash pine.

Some types of figure are more pronounced in plain-sawed lumber and others in quarter-sawed (table 2). Often lumber is neither strictly plain-sawed nor strictly quarter-sawed but rather is intermediate, thereby losing some of its decorative effect.

In plain-sawed boards and rotary-cut veneer the annual growth rings frequently form ellipses and parabolas that make striking figures, especially when the rings are irregular in width and outline on the cut surface. On quarter-sawed surfaces these rings form stripes, which are not especially ornamental unless they are irregular in width and direction. The relatively large rays, often referred to as flakes, form a conspicuous figure in quarter-sawed oak and sycamore. With interlocked grain, which slopes in alternate directions in successive layers from the center of the tree outward, quarter-sawed surfaces show a ribbon effect, either because of the difference in reflection of light from successive layers when the wood has a natural luster or because cross grain of varying degree absorbs stains unevenly. Much of this type of figure is lost in plain-sawed lumber.

In open-grained hardwoods, the appearance of both plain-sawed and quarter-sawed lumber can be varied greatly by the use of fillers of different colors. In softwoods the annual growth layers can be made to stand out more by applying a stain.

Knots, pin wormholes, bird pecks, birdseye, mineral streaks, sworls, and bark are decorative in some species when the wood is carefully selected for a particular architectural treatment.

IDENTIFICATION OF WOOD

Familiarity with most kinds of wood makes it possible to identify them by their general appearance. In the technical identification of wood and for instruction purposes, specific differences must be pointed out. Some woods, such as black walnut, can readily be identified by their color; others, such as Douglas fir, cypress, and the cedars, can be distinguished by their odor. Many woods have a pronounced difference in color between sapwood and heartwood, whereas in others there is no difference in color. Pitch is found normally only in the pines, Douglas fir, the spruces, larch, and tamarack. Frequently it is necessary to refer to the finer details of the structure, such as the size of the rays, the size and arrangement of the pores, and the presence or absence of resin ducts, for accurate identification. (Koehler's four publications on identification of woods, Penhallow, and Record.)

GRAIN AND TEXTURE OF WOOD

The terms "grain" and "texture" are commonly used rather loosely in connection with wood. In fact, they do not have any definite meaning. Grain is often made to refer to the annual rings, as in fine grain and coarse grain, but it is also employed to indicate the direction of the fibers, as in straight grain, spiral grain, and curly grain. Painters refer to woods as open-grained and close-grained, meaning thereby the relative size of the pores, which determines whether the piece needs a filler. Texture is often used synonymously with grain, but usually it refers to the finer structure of the wood rather than to the annual rings. When the words "grain" or "texture" are used in connection with wood, the meaning intended should be made perfectly clear (Koehler, Properties and Uses of Wood).

PLAIN-SAWED AND QUARTER-SAWED LUMBER

Lumber can be cut from a log in two distinct ways, namely, tangent to the annual rings, producing what is known as "plain-sawed" lumber in hardwoods and "flat-grain" or "slash-grain" lumber in softwoods, and parallel to the radiuses, or rays, producing what is known as "quarter-sawed" lumber in hardwoods and "edge-grain" or "vertical-grain" lumber in softwoods (fig. 4). Usually so-called quarter-sawed or edge-grain lumber is not cut strictly parallel with the rays; and often in plain-sawed boards the surfaces next to the edges are far from being tangent to the rings. It is commercial practice to call material with rings from 45° to 90° with the surface quarter-sawed, while material with rings from 0° to 45° with the surface is called plain-sawed. Hardwood lumber in which the annual rings make angles of 30° to 60° with the faces is sometimes called "bastard sawn."

Following are some of the advantages of plain-sawed or flat-grain lumber:

(1) It is cheaper, as a rule, because it requires less time and involves less waste in cutting.

(2) The figure resulting from the annual rings and also some other types of figure are brought out most conspicuously.

(3) Round or oval knots which may occur in plain-sawed boards affect the surface appearance less than spike knots which may occur in quarter-sawed boards. Also a board with a round or oval knot is weakened less by the knot than a board with a spike knot. However, a greater percentage of the boards from a log sawed to produce the maximum amount of plain-sawed lumber will contain knots than do boards from a log sawed to produce the maximum amount of quarter-sawed material.

(4) Shakes and pitch pockets when present extend through fewer boards.

(5) It does not collapse so easily in drying.

Following are the principal advantages of quarter-sawed or edge-grain lumber:

(1) It shrinks and swells less in width.

(2) It twists and cups less.

(3) It does not surface check or split so badly in seasoning and in use.

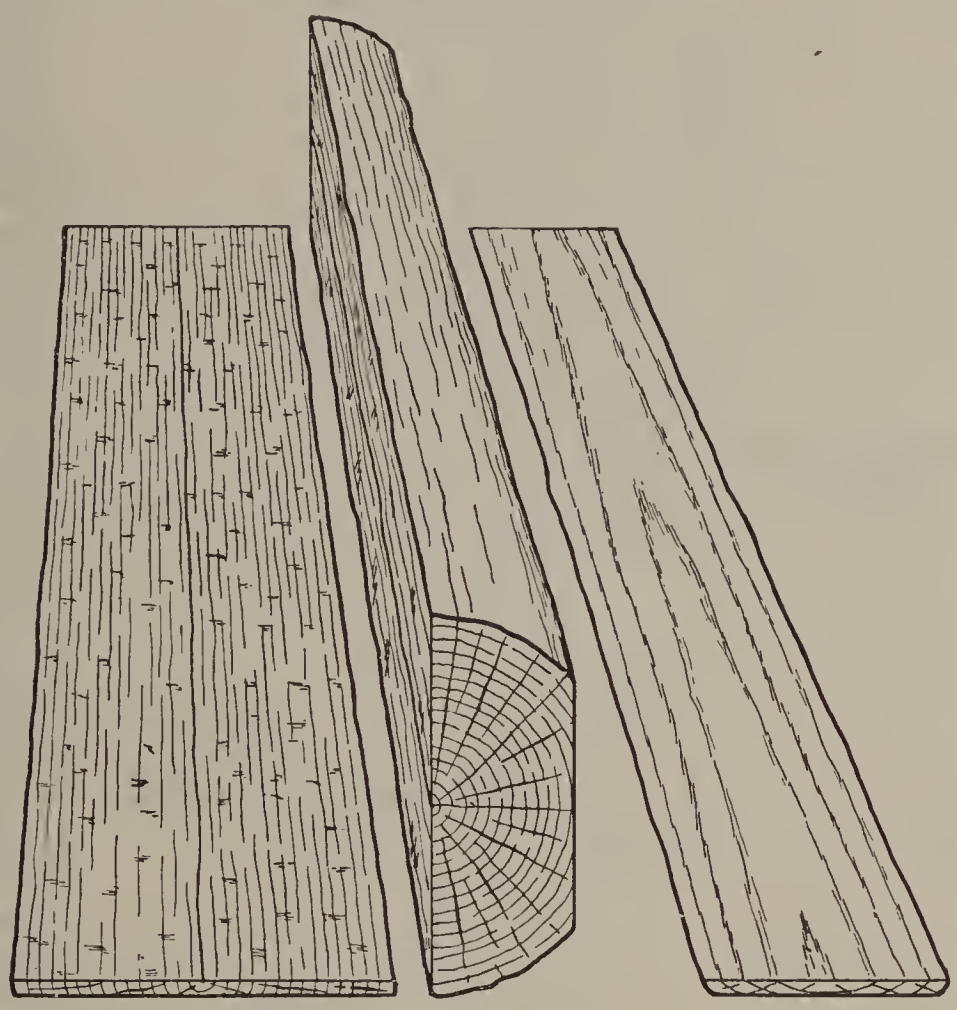


FIGURE 4.—Quarter-sawed (*A*) and plain-sawed (*B*) boards cut from log.

(4) Raised grain caused by the annual rings does not become so pronounced.

(5) It wears more evenly.

(6) Types of figure coming from pronounced rays, interlocked grain, and wavy grain are brought out most conspicuously.

(7) It does not allow liquids to pass into or through it so readily.

(8) It holds paint better in some species.

(9) The width of the sapwood appearing in a board is limited according to the width of the sapwood in the log.

WEATHERING OF WOOD

Boards exposed to the weather without protective coating rapidly become weathered. Weathering may involve change in color, roughening and checking of the surface, and, if one side of the board only is fully exposed, cupping and tearing loose from fastenings, but it does not include decay. With all species, edge-grain boards check less conspicuously and cup less than flat-grain boards of the same species. Twisting, another although less common effect of weathering, is caused primarily by uneven shrinkage resulting from spiral

and interlocked grain; it is more pronounced in plain-sawed than in quarter-sawed boards. Weathering, as a rule, changes all woods to a gray color, darker in some woods than in others, and attractive when accompanied by a silvery sheen, as it often is.

Woods that weather with—	Light-gray color and silvery sheen	Cedar, Alaska
		Cedar, Port Orford
		Cypress, southern
	Light-gray color and moderate sheen	Aspen
		Basswood
		Birch
		Cottonwood
		Gum, red
		Hemlock, eastern
		Hemlock, western
		Hickory
		Maple
		Pine, northern white
		Pine, ponderosa
		Pine, sugar
		Pine, western white
		Poplar, yellow
		Spruce, eastern
		Spruce, Sitka
	Dark-gray color and little or no sheen	Ash
		Cedar, western red
		Chestnut
		Douglas fir
		Fir, commercial white
		Larch, western
		Oak, red
		Oak, white
		Pine, southern yellow
		Redwood
		Walnut, black
Woods on which weather checks are—	Inconspicuous	Aspen
		Cedar, Alaska
		Cedar, Port Orford
		Cedar, western red
		Cypress, southern
		Poplar, yellow
		Redwood
	Conspicuous	Ash
		Basswood
		Birch
		Chestnut
		Cottonwood
		Douglas fir
		Fir, commercial white
		Gum, red
		Hemlock, eastern
		Hemlock, western
		Hickory
		Larch, western
		Maple
		Oak, red
		Oak, white
		Pine, northern white
		Pine, ponderosa
		Pine, southern yellow
		Pine, sugar
		Pine, western white
		Spruce, eastern
		Spruce, Sitka
		Walnut, black

Woods that cup and tend to pull loose from fastenings when exposed to the weather.	Slight	Cedar, Alaska Cedar, Port Orford Cedar, western red Cypress, southern Redwood
	Distinct	Aspen Basswood Douglas fir Fir, commercial white Hemolck, eastern Hemlock, western Larch, western Pine, northern white Pine, ponderosa Pine, southern yellow Pine, sugar Pine, western white Poplar, yellow Spruce, eastern Spruce, Sitka
	Pronounced	Chestnut Walnut, black
	Very pronounced	Ash Birch Cottonwood Gum, red Hickory Maple Oak, red Oak, white
Woods likely to twist because of interlocked grain when exposed to the weather.		Birch Cottonwood Elm Gum, black Gum, red Gum, tupelo Sycamore Many tropical hardwoods

Spiral grain, another cause of twisting, may occur sporadically in any species.

DECAY RESISTANCE OF HEARTWOOD OF DIFFERENT NATIVE SPECIES WHEN USED UNDER CONDITIONS THAT FAVOR DECAY

Wood kept either constantly dry or continuously submerged in water does not decay, regardless of species or of the presence of sapwood. A large proportion of the wood in use is kept so dry at all times that it lasts indefinitely. Moisture and temperature, which vary greatly with local conditions, are the principal factors affecting the rate of decay. When exposed to conditions that favor decay, wood in warm, humid areas of the United States deteriorates more rapidly than that in cool or dry areas. High altitudes, as a rule, are less favorable to decay than are low altitudes because the average temperatures are lower and the growing seasons for fungi, which cause decay, are shorter.

The natural decay resistance of all common native species of wood lies in the heartwood. When untreated, the sapwood of substantially all species has low resistance to decay and usually has a short life under decay-producing conditions. The decay resistance or durability of heartwood in service is greatly affected by differences

in the character of the wood, the attacking fungus, and the conditions of exposure. A widely different length of life may therefore be obtained from pieces of wood cut from the same species or even the same tree and used under apparently similar conditions. Further, in a few species, such as the spruces and the white firs (not Douglas fir), the colors of the heartwood and of the sapwood are so similar that frequently the two cannot be easily distinguished.

Comparisons of the relative decay resistance of different species must be estimates. They cannot be exact; and they may be extremely misleading, if considered mathematically accurate and universally applicable. Such comparisons may be useful, however, if regarded as approximate averages only, from which individual pieces or lots of a given species may vary considerably, and if they are understood to apply only where the wood is subject to conditions that favor decay.

The following grouping divides some of the more common native species into five classes listed in accordance with the resistance of heartwood to decay; every grouping of this nature is subject to the preceding limitations. The classification is based on service records, when they are available, and on general experience.

Heartwood durable even when used under conditions that favor decay	Cedar, Alaska Cedar, eastern red Cedar, northern white Cedar, Port Orford Cedar, southern white Cedar, western red Chestnut Cypress, southern Locust, black Osage-orange Redwood Walnut, black Yew, Pacific
Heartwood of intermediate durability but nearly as durable as some of the species named in the high-durability group	Douglas fir (dense) Honey locust Oak, white Pine, southern yellow (dense)
Heartwood of intermediate durability	Douglas fir (unselected) Gum, red Larch, western Pine, southern yellow (unselected) Tamarack
Heartwood between the intermediate and the nondurable group	Ash, commercial white Beech Birch, sweet Birch, yellow Hemlock, eastern Hemlock, western Hickory Maple, sugar Oak, red Spruce, black Spruce, Engelmann Spruce, red Spruce, Sitka Spruce, white
Heartwood low in durability when used under conditions that favor decay	Aspen Basswood Cottonwood Fir, commercial white Willow, black

There are no adequate service records from which to evaluate the heartwood of the white pines and ponderosa pine in decay resistance. There is a common opinion, as the result of general experience with the use of the white pines and ponderosa pine, that the heartwood of the white pines has more decay resistance and therefore will give longer service under conditions favoring decay than the heartwood of ponderosa pine.

THERMAL EXPANSION OF WOOD

Most substances expand more or less when heated. In the case of wood, the thermal expansion is so small as to be unimportant in ordinary usage. Different investigators are not in close agreement in their values for this property of wood, although they do agree that the expansion across the grain is much greater than that along the grain.

Table 3 shows the fractional amount per unit dimension by which various species may be expected to increase or decrease in heating or cooling 1° F.

TABLE 3.—*Coefficient of linear expansion of wood per degree Fahrenheit at ordinary temperatures*

Species of wood	Direction of expansion		Species of wood	Direction of expansion	
	Parallel to fibers	Across fibers		Parallel to fibers	Across fibers
Ash	[1] 0.0000053		Sugar maple	[2] 0.0000012	
Beech	[1] 0.0000014	[1] 0.0000341	Oak	[1] .0000027	[1] 0.0000302
Yellow birch	[2] .0000011		Red oak	[2] .0000019	
Yellow birch, tangential		[2] .0000178	Red oak, tangential		[2] .0000236
Yellow birch, radial		[2] .0000146	Red oak, radial		[2] .0000157
Chestnut	[1] .0000036	[1] .0000181	Pine	[1] .0000030	[1] .0000189
Elm	[1] .0000031	[1] .0000246	Yellow poplar, tangential		[2] .0000166
Mahogany	[1] .0000020	[1] .0000224	Yellow poplar, radial		[2] .0000157
Maple	[1] .0000035	[1] .0000269	Walnut	[1] .0000036	[1] .0000269

[1] Calculated from Smithsonian Physical Tables.
[2] Forest Products Laboratory.

THERMAL CONDUCTIVITY OF WOOD

The thermal conductivity of wood (Rowley) varies with species, the heavier kinds having higher conductivity values. Since thermal conductivity is inversely proportional to heat-insulating value, the lighter species are the better insulators. Thermal-conductivity values are given in table 4 rather than heat-insulating values because of the comparative ease of determination. A more detailed discussion of the thermal conductivity of wood is given on pages 299 to 305.

ELECTRICAL RESISTANCE OF WOOD

The electrical resistance of wood (Hasselblatt, Hiruma, and Stamm) varies greatly with change in moisture content, especially below the fiber-saturation point, decreasing as the moisture content increases. It also varies slightly with species, is greater across the grain than along it, and approximately doubles for each drop in temperature of 22.5° F.

TABLE 4.—*Thermal conductivity across the grain of different woods at moisture content indicated*

[T=mean temperature in degrees Fahrenheit; D=weight in pounds per cubic foot; K=thermal conductivity in British thermal units per hour and per square foot of conducting material, with a temperature gradient of 1° F. per inch of thickness.]

Species	Moisture content	T	D	K	Authority
	Percent	°*F.*	*Lb. per cu. ft.*	*B. t. u.*	
Ash, white	12	75	40.0	1.05	F. B. Rowley, University of Minnesota.
Balsa	-------	90	7.3	.33	Bureau of Standards.
Do	-------	90	8.8	.38	Do.
Do	-------	90	20.0	.58	Do.
Birch, yellow	12	75	43.0	1.00	F. B. Rowley, University of Minnesota.
Cedar, western red	12	75	25.0	.72	Do.
Cypress, southern	12	75	29.0	.83	Do.
Douglas fir	12	75	33.0	.77	Do.
Elm (soft)	12	75	32.5	.91	Do.
Fir, white	12	75	25.0	.65	Do.
Hemlock, eastern	12	75	28.5	.80	Do.
Hemlock, western	12	75	28.5	.76	Do.
Larch, western	12	75	39.0	.99	Do.
Maple (hard)	12	75	44.5	1.16	Do.
Maple (soft)	12	75	39.0	1.04	Do.
Oak, red	12	75	45.0	1.20	Do.
Oak, white	12	75	46.5	1.22	Do.
Pine, longleaf	12	75	38.0	.96	Do.
Pine, northern white	12	75	27.5	.83	Do.
Pine, Norway	12	75	30.0	.84	Do.
Pine, ponderosa	12	75	30.5	.85	Do.
Pine, shortleaf	12	75	34.0	.98	Do.
Pine, sugar	12	75	25.5	.69	Do.
Redwood	12	75	26.0	.76	Do.
Spruce, Sitka	12	75	26.5	.68	Do.

Table 5 lists the electrical resistance along the grain of some common species, at different uniform values of moisture content, between needle electrodes driven each time to the same depth. The specific resistances should be proportional to these values.

For estimating, where the correct value is not known, the moisture content of wood inside a heated building may be taken as about 8 percent in winter and about 11 percent in summer; wood out of doors and not subject to direct rainfall will usually have a moisture content of about 12 to 18 percent. A surface film of moisture, caused by condensation or rainfall, will lower the resistance of the surface of a dry piece to that of a piece with a moisture content of 25 percent or more.

The measurement of electrical resistance in a piece of wood containing an uneven distribution of moisture will be controlled by the electrode in the drier portion of the wood.

WEIGHTS OF VARIOUS WOODS

Table 6 shows the average weights of the more important commercial woods grown in the United States. The weights of wood when green, as here recorded, include the moisture present at the time the trees were felled, and are based on the average of heartwood and sapwood pieces as represented by test specimens taken from pith to the bark. The air-dry weights are for wood at a moisture content of 12 percent, which is approximately the condition reached without artificial heating by material sheltered from precipitation in the North Central States. The weights per thousand board

TABLE 5.—*The average electrical resistance along the grain in megohms, measured at 80° F. between 2 pairs of needle electrodes 1¼ inches apart and driven to a depth of 5/16 of an inch, of several species of wood at different values of moisture content*

Species of wood	Megohms when the moisture content in percent is—																		
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Conifers:																			
Cypress, southern	12,600	3,980	1,410	630	265	120	60	33	18.6	11.2	7.1	4.6	3.09	1.78	1.26	0.91	0.66	0.51	0.42
Douglas fir (coast region)	22,400	4,780	1,660	630	265	120	60	33	18.6	11.2	7.1	4.6	3.09	2.14	1.51	1.10	.79	.60	.46
Fir, California red	31,600	6,760	2,000	725	315	150	83	48	28.8	18.2	11.8	7.6	5.01	3.31	2.29	1.58	1.15	.83	.63
Fir, white	57,600	15,850	3,980	1,120	415	180	83	46	26.9	16.6	11.0	6.6	4.47	3.02	2.14	1.55	1.12	.86	.62
Hemlock, western	22,900	5,620	2,040	850	400	185	98	51	28.2	16.2	10.0	6.0	3.89	2.52	1.58	1.05	.72	.51	.37
Larch, western	39,800	11,200	3,980	1,445	560	250	120	63	33.9	19.9	12.3	7.6	5.02	3.39	2.29	1.62	1.20	.87	.66
Pine, longleaf	25,000	8,700	3,160	1,320	575	270	135	74	41.7	24.0	14.4	8.9	5.76	3.72	2.46	1.66	1.15	.79	.60
Pine, northern white	20,900	5,620	2,090	850	405	200	102	58	33.1	19.9	12.3	7.9	5.01	3.31	2.19	1.51	1.05	.74	.52
Pine, ponderosa	39,800	8,910	3,310	1,410	645	300	150	81	44.7	25.1	14.8	9.1	5.62	3.55	2.34	1.62	1.15	.87	.69
Pine, shortleaf	43,600	11,750	3,720	1,350	560	255	130	69	38.9	22.4	13.8	8.7	5.76	3.80	2.63	1.82	1.29	.93	.66
Pine, sugar	22,900	5,250	1,660	645	280	140	76	44	25.7	15.9	10.0	6.6	4.36	3.02	2.09	1.48	1.05	.75	.56
Redwood	22,400	4,680	1,550	615	250	100	45	22	12.6	7.2	4.7	3.2	2.29	1.74	1.32	1.05	.85	.71	.60
Spruce, Sitka	22,400	5,890	2,140	830	365	165	83	44	25.1	15.5	9.8	6.3	4.27	3.02	2.14	1.58	1.17	.91	.71
Hardwoods:																			
Ash, commercial white	12,000	2,190	690	250	105	55	28	14	8.3	5.0	3.2	2.0	1.32	.89	.63	.50	.44	.40	.40
Basswood	36,300	1,740	470	180	85	45	27	16	9.6	6.2	4.1	2.8	1.86	1.32	.93	.69	.51	.39	.31
Birch	87,000	19,950	4,470	1,290	470	200	96	53	30.2	18.2	11.5	7.6	5.13	3.55	2.51	1.78	1.32	.95	.70
Elm, American	18,200	2,000	350	110	45	20	12	7	3.9	2.3	1.5	1.0	.66	.48	.42	.40	.40	.40	.40
Gum, black [1]	31,700	12,600	5,020	1,820	725	275	120	58	27.6	13.0	6.9	3.7	2.19	1.38	.95	.63	.46	.33	.25
Gum, red	38,000	6,460	2,090	815	345	160	81	45	25.7	15.1	9.3	6.0	3.98	2.63	1.78	1.26	.87	.63	.46
Hickory, true		31,600	2,190	340	115	50	21	11	6.3	3.7	2.3	1.5	1.00	.71	.52	.44	.40	.40	.40
Khaya [2]	44,600	16,200	6,310	2,750	1,260	630	340	180	105.0	60.2	35.5	21.9	14.10	9.33	6.16	4.17	2.82	1.99	1.44
Magnolia	43,700	12,600	5,010	2,040	910	435	205	105	56.2	29.5	16.2	9.1	5.25	3.09	1.86	1.17	.74	.50	.32
Mahogany	20,900	6,760	2,290	870	380	180	85	43	22.4	12.3	7.2	4.4	2.69	1.66	1.07	.72	.49	.35	.26
Maple, sugar	72,400	13,800	3,160	690	250	105	53	29	16.6	10.2	6.8	4.5	3.16	2.24	1.62	1.23	.98	.75	.60
Oak, commercial red [1]	14,400	4,790	1,590	630	265	125	63	32	18.2	11.3	7.3	4.6	3.02	2.09	1.45	.95	.80	.63	.50
Oak, commercial white	17,400	3,550	1,100	415	170	80	42	22	12.6	7.2	4.3	2.7	1.70	1.15	.79	.60	.49	.44	.41
Poplar, yellow [1]	24,000	8,320	3,170	1,260	525	250	140	76	43.7	25.2	14.5	8.7	5.76	3.81	2.64	1.91	1.39	1.10	.85
Shorea [3]	2,890	690	220	80	35	15	9	5	2.8	1.7	1.1	.7	.45	.30	.21	.16	.12	.09	.07
Walnut, black	51,300	9,770	2,630	890	355	155	78	41	22.4	12.9	7.8	4.9	3.16	2.14	1.48	1.02	.72	.51	.38

[1] The values for this species were calculated from measurements on veneer.
[2] Known in the lumber trade as "African mahogany."
[3] A Philippine hardwood, identified as tanguile (*shorea polysperma* Merr.) or some similar species.

feet are based on nominal or full size. Since nominal and actual size of softwood lumber often vary considerably (p. 81), this difference must be taken into consideration in estimating the actual weight of softwood lumber per thousand board feet. For example, a nominal 1- by 8-inch softwood board actually measures about twenty-five thirty-seconds by 7½ inches, and the ratio between actual and nominal cross section is:

$$\frac{\frac{25}{32}\times 7\frac{1}{2}}{1\times 8}=0.732$$

Then the actual weight of 1,000 board feet of, for example, Sitka spruce 1- by 8-inch boards at 12-percent moisture is approximately $2{,}330\times 0.732=1{,}710$ pounds.

TABLE 6.—*Weights of commercially important woods grown in the United States*

Species	Weight per cubic foot		Weight per 1,000 board feet (nominal size) air-dry (12-percent moisture content)	Species	Weight per cubic foot		Weight per 1,000 board feet (nominal size) air-dry (12-percent moisture content)
	Green	Air-dry (12-percent moisture content)			Green	Air-dry (12-percent moisture content)	
	Lb.	*Lb.*	*Lb.*		*Lb.*	*Lb.*	*Lb.*
Alder, red	46	28	2,330	Hackberry	50	37	3,080
Ash, black	52	34	2,830	Hemlock, eastern	50	28	2,330
Ash, commercial white [1]	48	41	3,420	Hemlock, western	41	29	2,420
Ash, Oregon	46	38	3,160	Hickory, pecan [4]	62	45	3,750
Aspen	43	26	2,170	Hickory, true [5]	63	51	4,250
Basswood	42	26	2,170	Honeylocust	61	----	----
Beech	54	45	3,750	Larch, western	48	36	3,000
Birch [2]	57	44	3,670	Locust, black	58	48	4,000
Birch, paper	50	38	3,160	Magnolia, cucumber	49	33	2,750
Butternut	46	27	2,250	Magnolia, evergreen	59	35	2,920
Cedar, Alaska	36	31	2,580	Maple, bigleaf	47	34	2,830
Cedar, eastern red	37	33	2,750	Maple, black	54	40	3,330
Cedar, incense	45	----	----	Maple, red	50	38	3,170
Cedar, northern white	28	22	1,830	Maple, silver	45	33	2,750
Cedar, Port Orford	56	29	2,420	Maple, sugar	56	44	3,670
Cedar, southern white	26	23	1,920	Oak, red [6]	64	44	3,670
Cedar, western red	27	23	1,920	Oak, white [7]	63	47	3,920
Cherry, black	45	35	2,930	Pine, lodgepole	39	29	2,420
Chestnut	55	30	2,500	Pine, northern white	36	25	2,080
Cottonwood, eastern	49	28	2,330	Pine, Norway	42	34	2,830
Cottonwood, northern black	43	24	2,000	Pine, ponderosa	45	28	2,330
Cypress, southern	51	32	2,670	Pines, southern yellow:			
Douglas fir (coast region)	38	34	2,830	Pine, loblolly	53	36	3,000
Douglas fir ("Inland Empire" region)	36	31	2,580	Pine, longleaf	55	41	3,420
Douglas fir (Rocky Mountain region)	35	30	2,500	Pine, shortleaf	52	36	3,000
Elm, American	54	35	2,920	Pine, sugar	52	25	2,080
Elm, rock	53	44	3,670	Pine, western white	35	27	2,250
Elm, slippery	56	37	3,080	Poplar, yellow	38	28	2,330
Fir, balsam	45	25	2,080	Redwood	50	28	2,330
Fir, commercial white [3]	46	27	2,250	Spruce, eastern [8]	34	28	2,330
Gum, black	45	35	2,920	Spruce, Engelmann	39	23	1,920
Gum, red	50	34	2,830	Spruce, Sitka	33	28	2,330
Gum, tupelo	53	35	2,920	Sugarberry	48	36	3,000
				Sycamore	52	34	2,830
				Tamarack	47	37	3,080
				Walnut, black	58	38	3,170

[1] Average of biltmore white ash, blue ash, green ash, and white ash.
[2] Average of sweet birch and yellow birch.
[3] Average of lowland white fir and white fir.
[4] Average of bitternut hickory, nutmeg hickory, water hickory, and pecan.
[5] Average of bigleaf shagbark hickory, mockernut hickory, pignut hickory, and shagbark hickory.
[6] Average of black oak, laurel oak, pin oak, red oak, scarlet oak, southern red oak, swamp red oak, water oak, and willow oak.
[7] Average of bur oak, chestnut oak, post oak, swamp chestnut oak, swamp white oak, and white oak.
[8] Average of black spruce, red spruce, and white spruce.

All the data are based on the weights and volumes of small, clear specimens taken from the top 4 feet of 16-foot butt logs of typical trees. Wood thus selected probably averages a trifle heavier than pieces that include the pith or that are taken from top logs which usually are of low average density.

In any lot of lumber of a given species in the air-dry condition at 12-percent moisture, the weight per cubic foot will rarely vary more than 10 percent from the figure shown in table 6. In green material, on the other hand, the variation may occasionally be as great as 20 percent, owing to wide differences in moisture content. Particularly in the species that have a high moisture content in the sapwood, large variations in weight when green may occur, depending on the proportion of sapwood. Since young softwood trees contain a larger proportion of sapwood than old trees, their wood averages heavier when green.

The greatest changes in weight are those which occur in the early stages of drying of green wood. Changes in the moisture content of air-dry wood are attended by only relatively small changes in weight per cubic foot, owing to the counter effect of change in volume as a result of the accompanying shrinkage or swelling.

A practical rule for estimating the weight per unit volume of wood at a moisture content within 4 or 5 percent above or below 12 percent (table 6), is to regard a one-half percent change in weight per unit volume as accompanying a 1-percent change in moisture content. For example, wood at 8-percent moisture content would weigh about 2 percent less per unit volume than it would at 12-percent moisture content, and at 14-percent moisture content the weight per unit volume would be about 1 percent more than it would at 12-percent moisture content.

WORKING QUALITIES OF WOOD

In selecting wood for a given purpose the ease with which it may be worked is sometimes a factor, especially when hand tools are to be used. No test has been devised for definitely classifying woods as to workability, and the following classification is therefore based on the experience of the Forest Products Laboratory together with the general reputation of the wood (table 7).

TABLE 7.—*Ease of working with hand tools*

SOFTWOODS

Easy to work	Medium to work	Difficult to work
Cedar, incense	Cedar, eastern red	Douglas fir.
Cedar, northern white	Cypress, southern	Larch, western.
Cedar, Port Orford	Fir, balsam	Pine, southern yellow.
Cedar, southern white	Fir, white	
Cedar, western red	Hemlock, eastern	
Pine, northern white	Hemlock, western	
Pine, ponderosa	Pine, lodgepole	
Pine, sugar	Redwood	
Pine, western white	Spruce, eastern	
	Spruce, Sitka	

TABLE 7.—*Ease of working with hand tools*—Continued

HARDWOODS

Easy to work	Medium to work	Difficult to work
Alder, red	Birch, paper	Ash, commercial white.
Basswood	Cottonwood	Beech.
Butternut	Gum, black	Birch.
Chestnut	Gum, red	Cherry.
Poplar, yellow	Gum, tupelo	Elm.
	Magnolia	Hackberry.
	Sycamore	Hickory, true and pecan.
	Walnut, black	Honeylocust.
		Locust, black.
		Maple.
		Oak, commercial red.
		Oak, commercial white.

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STRENGTH VALUES OF CLEAR WOOD AND RELATED FACTORS

STRENGTH VALUES

Truly representative strength values for any species are preferably obtained from tests on small, clear pieces of wood because the effect of defects is then eliminated. Table 8 gives the strength properties of the more commercially important species; information on additional species is given in United States Department of Agriculture Bulletin 556 and Technical Bulletin 158.[6] The data are based on tests of specimens 2 by 2 inches in cross section and of different lengths, depending upon the test. The standard testing procedure of the American Society for Testing Materials was followed.

Since there is a considerable difference in the strength of small clear pieces of wood when green and when air-dry, strength values are given for both conditions. The normal increase in strength with seasoning shown in table 8, however, does not hold for large pieces because the development of checks in and around knots and of shakes and checks along the neutral axis during seasoning usually largely offset the increase in strength caused by drying. For allowable working stresses for various species see p. 102.

EXPLANATION OF TABLE 8

Column 1, Common and Botanical Names of Species

Many of the species have numerous common names, and not infrequently one common name is applied to several species. This leads to so much confusion that it is necessary to refer to a standard nomenclature. The common and botanical names used in the tables are the official names of the United States Forest Service.

Column 2, Moisture Content

Moisture content is the weight of water contained in the wood, expressed as a percentage of the weight of the oven-dry wood.

The moisture content given for green material is the average for specimens taken from the pith to the circumference of the log and hence represents a combination of the moisture as found in the heartwood and in the sapwood. In many species there is much more moisture in the sapwood than in the heartwood.

The moisture content of the air-dry material when tested varied somewhat among the different species. To facilitate comparison of strength properties, the test values were adjusted to conform to the uniform condition of 12 percent moisture as indicated.

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[6] For further information, the references at the end of this section should be consulted.

TABLE 8.—*Strength properties of some commercially important woods grown in the United States*

[Results of tests on small,[1] clear specimens in the green and air-dry condition [2]]

Commercial and botanical name of species	Moisture content	Specific[3] gravity	Static bending					Impact bending		Compression parallel to grain		Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength	Hardness	
			Fiber stress at proportional limit	Modulus of—		Work to—		Fiber stress at proportional limit	Height of drop causing complete failure (50-pound hammer)	Fiber stress at proportional limit	Maximum crushing strength			Load required to embed a 0.444-inch ball to ½ its diameter	
				Rupture	Elasticity	Proportional limit	Maximum load							End	Side
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Percent		*Lb. per sq. in.*	*Lb. per sq. in.*	*1,000 lb. per sq. in.*	*In.-lb. per cu. in.*	*In.-lb. per cu. in.*	*Lb. per sq. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb.*	*Lb.*
Alder, red (*Alnus rubra*)	98	0.37	3,800	6,500	1,170	0.70	8.0	8,000	22	2,620	2,960	310	770	550	440
	12	.41	6,900	9,800	1,380	1.85	8.4	11,600	20	4,530	5,820	540	1,080	980	590
Ash, black (*Fraxinus nigra*)	85	.45	2,600	6,000	1,040	.41	12.1	----------	33	1,690	2,300	430	860	590	------
	12	.49	7,200	12,600	1,600	1.57	14.9	----------	35	4,520	5,970	940	1,570	1,150	------
Ash, commercial white [4] (*Fraxinus* sp.)	43	.54	5,300	9,500	1,400	1.14	14.7	12,800	37	3,360	4,060	860	1,350	1,010	940
	12	.58	8,900	14,600	1,680	2.68	15.6	17,000	40	5,580	7,280	1,510	1,920	1,680	1,260
Ash, Oregon (*Fraxinus oregona*)	48	.50	4,200	7,600	1,130	.92	12.2	8,900	39	2,760	3,510	650	1,190	850	790
	12	.55	7,000	12,700	1,360	2.08	14.4	13,300	33	4,100	6,040	1,540	1,790	1,430	1,160
Aspen (*Populus tremuloides*)	94	.35	3,200	5,100	860	.69	6.4	7,000	22	1,670	2,140	220	660	280	300
	12	.38	5,600	8,400	1,180	1.53	7.6	9,000	21	3,040	4,250	460	850	510	350
Basswood (*Tilia glabra*)	105	.32	2,700	5,000	1,040	.40	5.3	6,300	16	1,690	2,220	210	600	290	250
	12	.37	5,900	8,700	1,460	1.37	7.2	9,800	16	3,800	4,730	450	990	520	410
Beech (*Fagus grandifolia*)	54	.56	4,300	8,600	1,380	.85	11.9	11,500	43	2,550	3,550	670	1,290	970	850
	12	.64	8,700	14,900	1,720	2.63	15.1	16,000	41	4,880	7,300	1,250	2,010	1,590	1,300
Birch [5] (*Betula* sp.)	62	.57	4,400	8,700	1,560	.79	15.9	11,100	48	2,640	3,510	550	1,160	910	850
	12	.63	10,100	16,700	2,070	2.83	19.8	20,000	52	6,200	8,310	1,250	2,020	1,660	1,340
Birch, paper (*Betula papyrifera*)	65	.48	3,000	6,400	1,170	.45	16.2	8,000	49	1,640	2,360	340	840	470	560
	12	.55	6,900	12,300	1,590	1.80	16.0	12,400	34	3,610	5,690	740	1,210	890	910
Butternut (*Juglans cinerea*)	104	.36	2,900	5,400	970	.52	8.2	7,300	24	2,020	2,420	270	760	410	390
	12	.38	5,700	8,100	1,180	1.59	8.2	11,200	24	4,200	5,110	570	1,170	570	490
Cedar, Alaska (*Chamaecyparis nootkatensis*)	38	.42	3,800	6,400	1,140	.77	9.2	9,100	27	2,500	3,050	430	840	540	440
	12	.44	7,100	11,100	1,420	2.06	10.4	12,200	29	5,210	6,310	770	1,130	790	580
Cedar, eastern red (*Juniperus virginiana*)	35	.44	3,400	7,000	650	1.08	15.0	7,000	35	2,540	3,570	860	1,010	760	650
	12	.47	3,800	8,800	880	1.01	8.3	8,500	22	----------	6,020	1,140	----------	900	------
Cedar, incense (*Libocedrus decurrens*)	108	.35	3,900	6,200	840	.94	6.4	7,300	17	2,940	3,150	460	830	570	390
	12	------	5,900	8,000	1,040	1.67	5.4	9,600	17	4,760	5,200	730	880	830	470

Cedar, northern white (*Thuja occidentalis*)	55	.29	2,600	4,200	640	.60	5.7	5,300	15	1,490	1,990	290	620	320	230
	12	.31	4,900	6,500	800	1.72	4.8	7,100	12	2,630	3,960	380	850	450	320
Cedar, Port Orford (*Chamaecyparis lawsoniana*)	43	.40	4,000	6,200	1,420	.65	7.4	9,200	22	2,770	3,130	350	830	460	400
	12	.42	7,700	11,300	1,730	1.97	9.1	13,500	28	5,890	6,470	760	1,080	730	560
Cedar, southern white (*Chamaecyparis thyoides*)	35	.31	2,500	4,700	750	.51	5.9	6,000	18	1,660	2,390	300	690	400	290
	12	.32	4,800	6,800	930	1.46	4.1	7,600	13	2,740	4,700	500	800	520	350
Cedar, western red (*Thuja plicata*)	37	.31	3,200	5,100	920	.63	5.0	6,900	17	2,470	2,750	340	710	430	270
	12	.33	5,300	7,700	1,120	1.44	5.8	8,600	17	4,360	5,020	610	860	660	350
Cherry, black (*Prunus serotina*)	55	.47	4,200	8,000	1,310	.80	12.8	10,200	23	2,940	3,540	440	1,130	750	660
	12	.50	9,000	12,300	1,490	3.11	11.4	13,600	29	5,960	7,110	850	1,700	1,470	950
Chestnut (*Castanea dentata*)	122	.40	3,100	5,600	930	.59	7.0	7,900	24	2,080	2,470	380	800	530	420
	12	.43	6,100	8,600	1,230	1.78	6.5	10,700	19	3,780	5,320	760	1,080	720	540
Cottonwood, eastern (*Populus deltoides*)	111	.37	2,900	5,300	1,010	.49	7.3	7,200	21	1,740	2,280	240	680	380	340
	12	.40	5,700	8,500	1,370	1.39	7.4	7,300	20	3,490	4,910	470	930	580	430
Cottonwood, northern black (*Populus trichocarpa hastata*)	132	.32	2,900	4,800	1,070	.44	5.0	6,800	20	1,760	2,160	200	600	280	250
	12	.35	5,300	8,300	1,200	1.25	6.7	9,800	22	3,270	4,420	370	1,020	540	350
Cypress, southern (*Taxodium distichum*)	91	.42	4,200	6,600	1,180	.91	6.6	8,800	25	3,100	3,580	500	810	440	390
	12	.46	7,200	10,600	1,440	2.15	8.2	10,400	24	4,740	6,360	900	1,000	660	510
Douglas fir (coast region) (*Pseudotsuga taxifolia*)	36	.45	4,800	7,600	1,550	.85	6.8	9,800	24	3,410	3,890	510	930	510	480
	12	.48	8,100	11,700	1,920	1.96	8.6	12,700	30	6,450	7,420	910	1,140	760	670
Douglas fir ("Inland Empire" region) (*Pseudotsuga taxifolia*)	42	.41	3,600	6,800	1,340	.55	6.9	8,700	22	2,460	3,240	500	870	530	470
	12	.44	7,400	11,300	1,610	1.91	8.6	11,800	27	5,520	6,700	950	1,190	720	630
Douglas fir (Rocky Mountain region) (*Pseudotsuga taxifolia*)	38	.40	3,600	6,400	1,180	.65	6.8	9,100	20	2,540	3,000	450	880	450	400
	12	.43	6,300	9,600	1,400	1.60	6.4	12,100	26	4,660	6,060	820	1,070	740	630
Elm, American (*Ulmus americana*)	89	.46	3,900	7,200	1,110	.81	11.8	------	38	1,920	2,910	440	1,000	680	------
	12	.50	7,600	11,800	1,340	2.53	13.0	------	39	4,030	5,520	850	1,510	1,110	------
Elm, rock (*Ulmus racemosa*)	48	.57	4,600	9,500	1,190	1.05	19.8	------	54	2,970	3,780	750	1,270	980	------
	12	.63	8,000	14,800	1,540	2.45	19.2	------	56	4,700	7,050	1,520	1,920	1,510	------
Elm, slippery (*Ulmus fulva*)	85	.48	4,000	8,000	1,230	.82	15.4	9,200	47	2,790	3,320	510	1,110	750	660
	12	.53	7,700	13,000	1,490	2.35	16.9	15,300	45	4,760	6,360	1,010	1,630	1,120	860
Fir, balsam (*Abies balsamea*)	117	.34	3,000	4,900	960	.52	4.7	6,900	16	2,080	2,400	210	610	290	290
	12	.36	5,200	7,600	1,230	1.23	5.1	7,800	20	3,970	4,530	380	710	510	400
Fir, commercial white [6] (*Abies* sp.)	108	.36	3,800	5,800	1,120	.75	5.3	8,300	22	2,470	2,810	360	750	390	340
	12	.38	6,300	9,300	1,470	1.55	7.0	11,200	20	3,870	5,380	610	930	710	460
Gum, black (*Nyssa sylvatica*)	55	.46	4,000	7,000	1,030	.91	8.0	9,800	30	2,490	3,040	600	1,100	790	640
	12	.50	7,300	9,600	1,200	2.54	6.2	14,500	22	3,470	5,520	1,150	1,340	1,240	810
Gum, red (*Liquidambar styraciflua*)	81	.44	3,700	6,800	1,150	.81	9.4	10,000	33	2,230	2,840	460	1,070	630	520
	12	.49	8,100	11,900	1,490	2.57	11.3	16,800	32	4,700	5,800	860	1,610	950	690
Gum, tupelo (*Nyssa aquatica*)	97	.46	4,200	7,300	1,050	.98	8.3	9,000	30	2,690	3,370	590	1,190	800	710
	12	.50	7,200	9,600	1,260	2.41	6.9	12,500	23	4,280	5,920	1,070	1,590	1,200	880
Hackberry (*Celtis occidentalis*)	65	.49	2,900	6,500	950	.58	14.5	7,900	48	2,070	2,650	490	1,070	760	700
	12	.53	5,900	11,000	1,190	1.72	12.8	13,700	43	3,710	5,440	1,100	1,590	1,110	880
Hemlock, eastern (*Tsuga canadensis*)	111	.38	3,800	6,400	1,070	.76	6.7	7,900	21	2,600	3,080	440	850	500	400
	12	.40	6,100	8,900	1,200	1.79	6.8	10,700	21	4,020	5,410	800	1,060	810	500

[1] Test specimens 2 by 2 inches in section. Bending specimens 30 inches long; others shorter depending on kind of test.

[2] The values in the first line for each species are from tests of green material; those in the second line are from tests of seasoned material adjusted to an average air dry condition of 12 percent moisture.

[3] Based on weight when oven dry and volume when green or at 12-percent moisture content.

[4] Average of Biltmore white ash (*Fraxinus biltmoreana*), blue ash (*F. quadrangulata*), green ash (*F. pennsylvanica lanceolata*), and white ash (*F. americana*).

[5] Average of sweet birch (*Betula lenta*) and yellow birch (*B. lutea*).

[6] Average of lowland white fir (*Abies grandis*) and white fir (*A. concolor*).

TABLE 8.—*Strength properties of some commercially important woods grown in the United States*—Continued

[Results of tests on small, clear specimens in the green and air-dry condition]

Commercial and botanical name of species	Moisture content	Specific gravity	Static bending					Impact bending		Compression parallel to grain		Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength	Hardness	
			Fiber stress at proportional limit	Modulus of—		Work to—		Fiber stress at proportional limit	Height of drop causing complete failure (50-pound hammer)	Fiber stress at proportional limit	Maximum crushing strength			Load required to embed a 0.444-inch ball to ½ its diameter	
				Rupture	Elasticity	Proportional limit	Maximum load							End	Side
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Percent		*Lb. per sq. in.*	*Lb. per sq. in.*	*1,000 lb. per sq. in.*	*In-lb. per cu. in.*	*In.-lb. per cu. in.*	*Lb. per sq. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb.*	*Lb.*
Hemlock, western (*Tsuga heterophylla*)	74	.38	3,400	6,100	1,220	.57	6.8	8,100	22	2,480	2,990	390	810	520	430
	12	.42	6,800	10,100	1,490	1.82	7.5	12,400	26	5,340	6,210	680	1,170	940	580
Hickory, pecan [7] (*Hicoria* sp.)	68	.59	5,300	9,900	1,380	1.18	19.3	14,200	60	3,810	4,320	980	1,260	1,274	1,308
	12	.65	9,100	16,300	1,780	2.61	18.8	20,900	57	6,360	8,280	2,040	1,770	1,930	1,820
Hickory, true [8] (*Hicoria* sp.)	57	.65	6,100	11,300	1,570	1.34	28.9	15,700	88	3,650	4,570	1,080	1,360	------	------
	12	.73	10,900	19,700	2,180	3.07	27.2	22,900	75	------	8,970	2,310	2,140	------	------
Honey locust (*Gleditsia triacanthos*)	63	.60	5,600	10,200	1,290	1.40	12.6	11,800	47	3,320	4,420	1,420	1,660	1,440	1,390
	12	------	8,800	14,700	1,630	2.74	13.3	15,400	47	5,250	7,500	2,280	2,250	1,860	1,580
Larch, western (*Larix occidentalis*)	58	.48	4,600	7,500	1,350	1.01	7.1	9,400	24	3,250	3,800	560	920	470	450
	12	.52	7,900	11,900	1,710	2.46	8.0	15,100	32	5,950	7,490	1,080	1,360	1,110	760
Locust, black (*Robinia pseudoacacia*)	40	.66	8,800	13,800	1,850	2.36	15.4	18,300	44	6,120	6,800	1,430	1,760	1,640	1,570
	12	.69	12,800	19,400	2,050	4.62	18.4	21,100	57	6,800	10,180	2,260	2,480	1,580	1,700
Magnolia, cucumber (*Magnolia acuminata*)	80	.44	4,200	7,400	1,560	.66	10.0	9,300	30	2,810	3,140	410	990	600	520
	12	.48	8,000	12,300	1,820	1.98	12.2	14,700	35	4,840	6,310	710	1,340	950	700
Magnolia, evergreen (*Magnolia grandiflora*)	105	.46	3,600	6,800	1,110	.67	15.4	8,800	54	2,160	2,700	570	1,040	780	740
	12	.50	6,800	11,200	1,400	1.90	12.8	13,600	29	3,420	5,460	1,060	1,530	1,280	1,020
Maple, bigleaf (*Acer macrophyllum*)	72	.44	4,400	7,400	1,100	1.02	8.7	8,500	23	2,510	3,240	550	1,110	760	620
	12	.48	6,600	10,700	1,450	1.66	7.8	------	28	4,790	5,950	930	1,730	1,330	850
Maple, black (*Acer nigrum*)	65	.52	4,100	7,900	1,330	.70	12.8	10,200	48	2,800	3,270	740	1,130	940	840
	12	.57	8,300	13,300	1,620	2.39	12.5	13,500	40	4,600	6,680	1,250	1,820	1,700	1,180
Maple, red (*Acer rubrum*)	63	.49	3,800	7,700	1,390	.71	11.4	------	32	2,360	3,280	500	1,150	780	------
	12	.54	8,700	13,400	1,640	2.84	12.5	------	32	4,650	6,540	1,240	1,850	1,430	------
Maple, silver (*Acer saccharinum*)	66	.44	3,100	5,800	940	.61	11.0	6,800	29	1,930	2,490	460	1,050	670	590
	12	.47	6,200	8,900	1,140	1.90	8.3	12,400	25	4,360	5,220	910	1,480	1,140	700
Maple, sugar (*Acer saccharum*)	58	.56	5,100	9,400	1,550	1.03	13.3	12,200	40	2,850	4,020	800	1,460	1,070	970
	12	.63	9,500	15,800	1,830	2.76	16.5	20,600	39	5,390	7,830	1,810	2,330	1,840	1,450

Oak, red [9] (*Quercus* sp.)	80	.57	4,400	8,500	1,360	.85	12.6	10,800	43	2,590	3,520	800	1,220	1,050	1,030
	12	.63	8,400	14,400	1,810	2.30	15.0	17,000	43	4,610	6,920	1,260	1,830	1,490	1,300
Oak, white [10] (*Quercus* sp.)	70	.59	4,700	8,100	1,200	1.08	11.3	10,900	42	2,940	3,520	850	1,270	1,110	1,070
	12	.67	7,900	13,900	1,620	2.31	13.3	17,400	39	4,350	7,040	1,410	1,890	1,420	1,330
Pine, lodgepole (*Pinus contorta*)	65	.38	3,000	5,500	1,080	.49	5.6	7,200	20	2,110	2,610	310	680	320	330
	12	.41	6,700	9,400	1,340	1.97	6.8	9,600	20	4,310	5,370	750	880	530	480
Pine, northern white (*Pinus strobus*)	68	.34	3,100	5,000	1,020	.54	5.2	6,700	17	2,060	2,490	290	660	310	310
	12	.36	6,000	8,800	1,280	1.59	6.7	9,500	19	3,680	4,840	550	860	500	400
Pine, Norway (*Pinus resinosa*)	54	.44	3,700	6,400	1,380	.59	5.8	7,500	28	2,410	3,080	360	780	360	340
	12	.48	9,400	12,500	1,800	2.78	10.0	15,900	25	5,330	7,340	830	1,230	670	580
Pine, ponderosa (*Pinus ponderosa*)	91	.38	3,100	5,000	970	.59	5.1	6,800	20	2,070	2,400	360	680	300	310
	12	.40	6,300	9,200	1,260	1.85	6.6	9,800	17	4,060	5,270	740	1,160	550	450
Pines, southern yellow:															
Loblolly (*Pinus taeda*)	81	.47	4,100	7,300	1,410	.68	8.2	8,900	30	2,550	3,490	480	850	420	450
	12	.51	7,800	12,800	1,800	1.92	10.4	12,100	30	4,820	7,080	980	1,370	750	690
Longleaf (*Pinus palustris*)	63	.54	5,200	8,700	1,600	.95	8.9	10,100	35	3,430	4,300	590	1,040	550	590
	12	.58	9,300	14,700	1,990	2.44	11.8	15,400	34	6,150	8,440	1,190	1,500	920	870
Shortleaf (*Pinus echinata*)	81	.46	3,900	7,300	1,390	.63	8.2	8,600	30	2,500	3,430	440	850	410	440
	12	.51	7,700	12,800	1,760	1.93	11.0	13,600	33	5,090	7,070	1,000	1,310	750	690
Pine, sugar (*Pinus lambertiana*)	137	.35	3,400	5,100	940	.70	5.4	7,400	17	2,330	2,530	350	680	320	310
	12	.36	5,700	8,000	1,200	1.53	5.5	10,700	18	4,140	4,770	590	1,050	530	380
Pine, western white (*Pinus monticola*)	54	.36	3,400	5,200	1,170	.56	5.0	7,600	19	2,430	2,650	290	640	310	310
	12	.38	6,200	9,500	1,510	1.47	8.8	11,900	23	4,480	5,620	540	----------	440	370
Poplar, yellow (*Liriodendron tulipifera*)	64	.38	3,400	5,400	1,090	.62	5.4	8,600	18	1,930	2,420	330	740	390	340
	12	.40	6,100	9,200	1,500	1.43	6.8	13,500	20	3,550	5,290	580	1,100	560	450
Redwood (virgin) (*Sequoia sempervirens*)	112	.38	4,800	7,500	1,180	1.18	7.4	8,900	21	3,700	4,200	520	800	570	410
	12	.40	6,900	10,000	1,340	2.04	6.9	10,200	19	4,560	6,150	860	940	790	480
Spruce, eastern [11] (*Picea sp.*)	46	.38	3,300	5,600	1,110	.57	6.5	7,000	21	2,120	2,600	290	710	390	340
	12	.40	6,500	10,100	1,440	1.68	8.4	11,400	22	4,160	5,590	590	1,070	630	490
Spruce, Engelmann (*Picea engelmannii*)	100	.31	2,500	4,200	830	.43	4.9	5,800	14	1,680	1,980	290	590	250	240
	12	.33	6,000	8,500	1,160	1.64	5.6	9,000	15	3,580	4,580	640	1,010	450	310
Spruce, Sitka (*Picea sitchensis*)	42	.37	3,300	5,700	1,230	.53	6.3	8,400	24	2,240	2,670	340	760	430	350
	12	.40	6,700	10,200	1,570	1.62	9.4	11,400	25	4,780	5,610	710	1,150	760	510
Sugarberry (*Celtis laevigata*)	62	.47	3,200	6,600	810	.78	12.0	8,200	33	1,990	2,800	580	1,050	840	740
	12	.51	6,200	9,900	1,140	2.18	11.2	11,600	36	3,970	5,620	1,240	1,280	1,280	960
Sycamore (*Platanus occidentalis*)	83	.46	3,300	6,500	1,060	.60	7.5	8,800	26	2,400	2,920	450	1,000	700	610
	12	.49	6,400	10,000	1,420	1.66	8.5	10,500	26	3,710	5,380	860	1,470	920	770
Tamarack (*Larix laricina*)	52	.49	4,200	7,200	1,240	.84	7.2	7,800	28	2,930	3,480	480	860	400	380
	12	.53	8,000	11,600	1,640	2.19	7.1	12,500	23	4,780	7,160	990	1,280	670	590
Walnut, black (*Juglans nigra*)	81	.51	5,400	9,500	1,420	1.16	14.6	11,900	37	3,520	4,300	600	1,220	960	900
	12	.55	10,500	14,600	1,680	3.70	10.7	16,400	34	5,780	7,580	1,250	1,370	1,050	1,010

[7] Average of bitternut hickory (*Hicoria cordiformis*), nutmeg hickory (*H. myristicaeformis*), water hickory (*H. aquatica*), and pecan (*H. pecan*).

[8] Average of bigleaf shagbark hickory (*Hicoria laciniosa*), mockernut hickory (*H. alba*), pignut hickory (*H. glabra*), and shagbark hickory (*H. ovata*).

[9] Average of black oak (*Quercus velutina*), laurel oak (*Q. laurifolia*), pin oak (*Q. palustris*), red oak (*Q. borealis*), scarlet oak (*Q. coccinea*), southern red oak (*Q. rubra*), swamp red oak (*Q. rubra pagodaefolia*), water oak (*Q. nigra*), and willow oak (*Q. phellos*).

[10] Average of bur oak (*Quercus macrocarpa*), chestnut oak (*Q. montana*), post oak (*Q. stellata*), swamp chestnut oak (*Q. prinus*), swamp white oak (*Q. bicolor*), and white oak (*Q. alba*).

[11] Average of black spruce (*Picea mariana*), red spruce (*P. rubra*), and white spruce (*P. glauca*).

Column 3, Specific Gravity

The weight of wood in a given volume changes with the shrinkage and swelling caused by changes in moisture. Consequently, specific gravity is an indefinite quantity unless the circumstances under which it is determined are specified. The two specific-gravity figures opposite each species in table 8 are based on the weight of the wood when oven-dry, the upper value being based on its volume when green, and the lower value on its volume at 12 percent moisture content.

Columns 4, 5, 6, 7, and 8, Static Bending

Fiber Stress at Proportional Limit

Fiber stress at proportional limit is the stress at which, under the testing procedure employed, the load-deformation curve departs from a straight line.

modulus of rupture

Modulus of rupture is the value obtained by using the moment at maximum load in the formula

$$S=\frac{Mc}{I}$$

Each value listed in column 5 of table 8 is a measure of the ability of a beam to support a slowly applied load for a few minutes.

modulus of elasticity

The modulus of elasticity is a measure of the stiffness or rigidity of a material. For a beam, modulus of elasticity is a measure of its resistance to deflection.

work in bending to proportional limit

Work to proportional limit in static bending is a measure of the work that a beam is able to resist or the shock that it can absorb without being stressed beyond the proportional limit as determined under slowly applied loads.

work in bending to maximum load

Work to maximum load in static bending represents the ability of the timber to absorb shock with some permanent deformation and with more or less injury to the timber. Work to maximum load is a measure of the combined strength and toughness of a material under bending stresses.

Columns 9 and 10, Impact Bending

fiber stress at proportional limit

For a definition of fiber stress at proportional limit see above. Fiber stress at proportional limit in impact is approximately double the fiber stress at proportional limit in static bending. This is an expression of the fact that a small beam, if suddenly strained, bends approximately twice as far to the proportional limit as when loaded slowly.

HEIGHT OF DROP CAUSING COMPLETE FAILURE

In the impact test a hammer of a given weight is dropped upon a beam from successively increased heights until complete rupture occurs. Height of drop is the maximum or the last drop of the hammer that causes failure (American Society for Testing Materials). It represents a quality important in articles that are occasionally stressed under shock beyond their proportional limit, such as handles and vehicle and implement parts.

Columns 11 and 12, Compression Parallel to Grain

FIBER STRESS AT PROPORTIONAL LIMIT

Fiber stress at proportional limit in compression parallel to the grain is little used because it is usually more convenient to use maximum crushing strength, which is less variable and easier to obtain. (See fiber stress at proportional limit, p. 54.)

MAXIMUM CRUSHING STRENGTH

The maximum crushing strength is the maximum ability of a short block to sustain a slowly applied end load. It is obtained by dividing the maximum load obtained in the test by the area of cross section of the block. This property is important in estimating the strength of short columns and those of intermediate length.

Column 13, Compression Perpendicular to Grain

For a definition of fiber stress at proportional limit see page 54. The safe bearing values used in computing the bearing area for beams, caps, stringers, and joists, and in selecting railroad ties are derived from the fiber stress at proportional limit in compression perpendicular to the fibers.

Column 14, Shearing Strength Parallel to Grain

Shearing strength parallel to the grain is a measure of the ability of timber to resist slipping of one part upon another along the grain. Shearing stress is produced in most uses of timber. It is most important in beams, where it is known as horizontal shear—the stress tending to cause the upper half of the beam to slide upon the lower.

Columns 15 and 16, Hardness

The measure of hardness is the load required to embed a 0.444-inch ball to one-half its diameter in the wood. The hardness test is applied to end, radial, and tangential surfaces of the timber. The values given in column 16 of table 8 are the averages of those for radial and tangential surfaces.

COMPRESSIVE STRESS PERPENDICULAR TO THE GRAIN AS RELATED TO WIDTH OF BEARING PLATE

Proportional-limit stresses in compression perpendicular to the grain as given in table 8 are from tests in which a load was applied through a plate 2 inches wide placed on the central 2 inches of a

specimen 6 inches long (American Society for Testing Materials). Because the wood fibers at the edges of the plate are thrown into tension by such an arrangement, the calculated stresses are higher than if the plate had been wider or the entire specimen had been covered, and conversely. The safe working stresses for bearing perpendicular to the grain, given on page 103, apply to bearings 6 inches or more in length anywhere along any side of a timber and to bearings of any length at the ends of members. For bearings less than 6 inches in length, placed away from the ends of a timber, higher stresses may be safely used. Correction factors for working stresses are given on page 104.

COMPRESSIVE STRENGTH PERPENDICULAR TO THE GRAIN AS RELATED TO PLACEMENT OF ANNUAL-GROWTH RINGS

Ordinarily little attention is paid to the direction of the load with respect to the annual-growth rings when wood is stressed in compression perpendicular to the grain (Jenkins). Investigation at the Forest Products Laboratory and elsewhere, however, has shown that under such loading the direction of the growth rings in species most commonly used for structural timbers influences the strength of the piece.

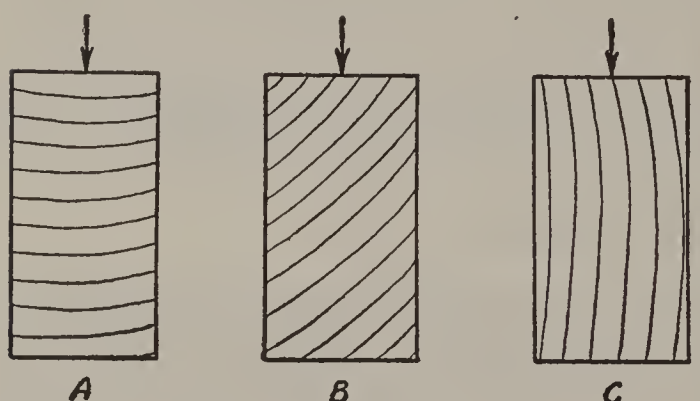


FIGURE 5.—The direction of the load in relation to the direction of the annual-growth rings: *A*, Perpendicular; *B*, 45°; *C*, parallel.

When the the load was applied, as in figure 5, *A*, the highest strength values were obtained; when applied as in figures 5, *B*, the lowest values, and as in figure 5, *C*, intermediate values. The softwoods are affected proportionately more by ring placement than are the hardwoods.

The effect of ring placement upon the modulus of elasticity in compression perpendicular to the grain, as indicated by a few tests on five different species, is illustrated in table 9.

The effect of ring placement upon the proportional limit was considerably less than it was upon modulus of elasticity. Tests on four softwoods showed that the proportional limit when the load was applied as in figure 5, *A*, was about twice that when the load was applied as in figure 5, *B*. Similarly the proportional limit of the softwoods when the load was applied as in figure 5, *C*, was about 1⅝ times that when the load was applied as in 5, *B*. Corresponding ratios for the hardwoods were somewhat smaller, being approximately 1⅞ and 1¼, respectively.

Maximum load was, in general, affected less than the proportional limit for both the softwoods and hardwoods.

COMPRESSIVE STRENGTH ON SURFACES INCLINED TO THE GRAIN

One of the more recently developed formulas for determining the compressive strength of wood on surfaces at an angle to the grain, known as the Hankinson formula (U. S. Army, Engineering Division), is recommended for general use in timber framing.

TABLE 9.—*Effect of ring placement upon modulus of elasticity in compression perpendicular to the grain*

Species	Direction of load in relation to the direction of annual growth rings	Moisture content	Specific gravity [1]	Modulus of elasticity perpendicular to the grain [2]
				Lb. per sq. in.
Douglas fir	Perpendicular	Green	0.40	76,000
	45°	do		12,000
	Parallel	do		56,000
Western hemlock	Perpendicular	do	.39	72,000
	45°	do		6,400
	Parallel	do		47,000
Redwood	Perpendicular	10 percent	.34	106,000
	45°	do		15,000
	Parallel	do		63,000
Sitka spruce	Perpendicular	12 percent	.39	111,000
	45°	do		11,000
	Parallel	11 percent		62,000
Yellow birch	Perpendicular	Green	.57	77,000
	45°	do		38,000
	Parallel	do		58,000
	Perpendicular	12 percent	.61	148,000
	45°	do		82,000
	Parallel	do		103,000

[1] Based on the volume of the wood at time of test and weight when oven dry.

[2] The modulus of elasticity in pounds per square inch parallel to the grain for the corresponding specifi gravities are as follows: Douglas fir, 1,890,000; western hemlock, 1,660,000; redwood, 1,320,000; Sitka spruce, 1,560,000; yellow birch, 1,570,000 and 2,060,000, respectively.

For safe working stresses the unit stress constants in the formula would be the working stresses in compression parallel and perpendicular to the grain for the species.

The formula is:

$$N=\frac{PQ}{P\sin^2\theta+Q\cos^2\theta}$$

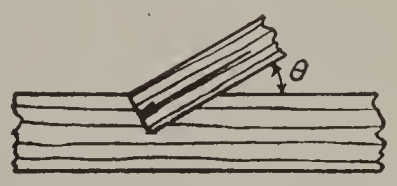


FIGURE 6.—The angle θ between the direction of the load and the direction of the grain.

in which N represents the allowable unit stress on the inclined surface; P, the unit stress in compression parallel to the grain; Q, the unit stress in compression perpendicular to the grain; and θ, the angle between the direction of the load and the direction of the grain (fig. 6).

SHEAR PARALLEL TO THE GRAIN

It is practically impossible to make a shear test that results in pure shear. In the block shear tests (American Society for Testing Materials) upon which the values in table 8 are based, there are components perpendicular to the grain and a nonuniform distribution of stress throughout the depth of the shear area, both of which influenced the results. These shear specimens (fig. 7) were notched so that a 2 by 2 inch portion is sheared from the side of a block 2 inches wide and 2½ inches long.

The values in table 8 are about 75 percent of the ultimate shear values obtained from torsion tests. They have no direct relationship to working stress for horizontal shear in beams (p. 103). Working

stresses for horizontal shear in beams are based on test results of full-sized timbers.

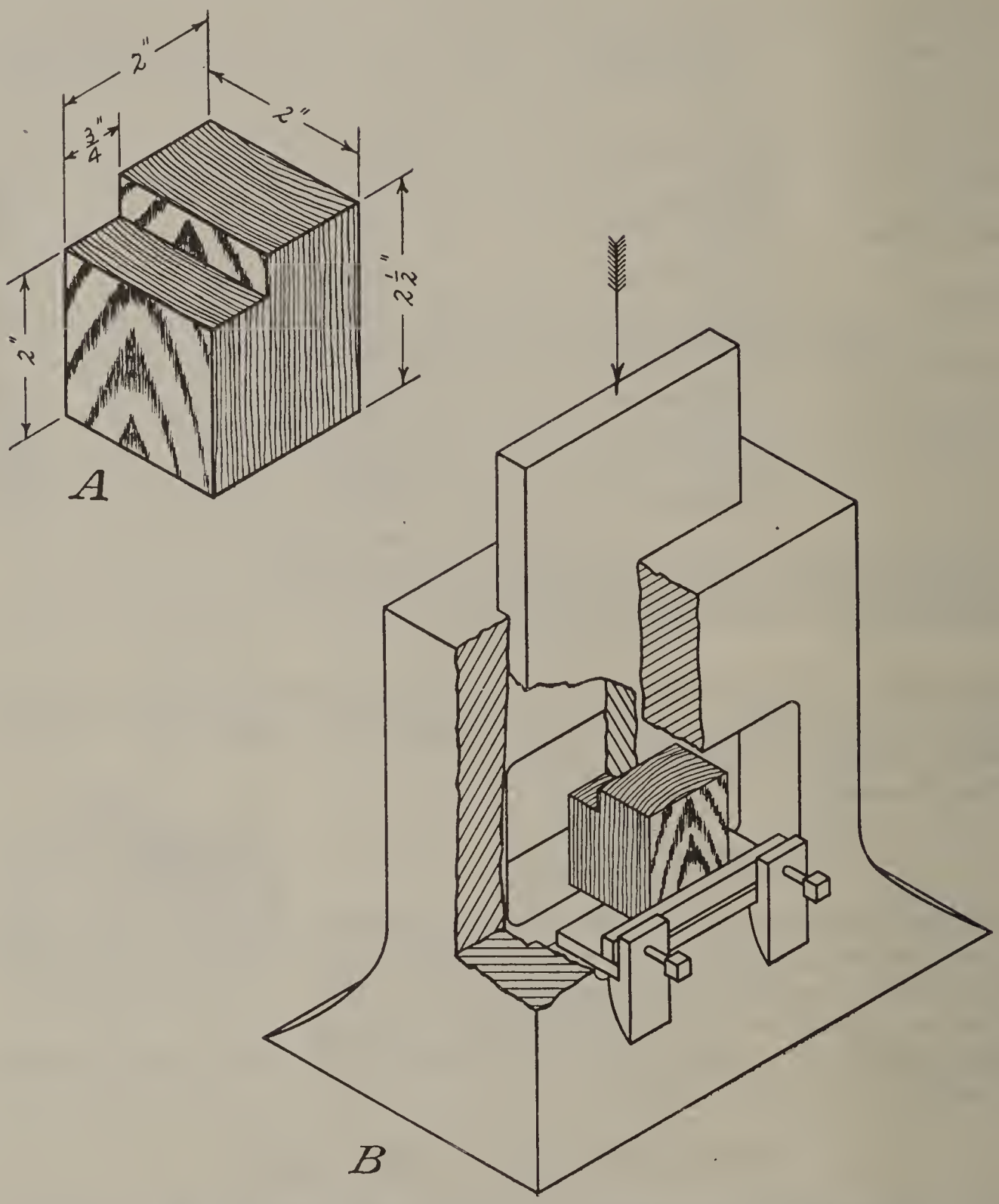


FIGURE 7.—Details of test specimen (*A*) used in shear-parallel-to-grain test (*B*).

TORSIONAL PROPERTIES

The torsional strength of wood (Carrington, and Trayer and March) is seldom needed in design, and, as a result, few data on this property are available. Torsional rigidity, while of some direct use, is needed primarily for estimating the critical buckling or twisting load of a compression member with thin outstanding parts (p. 165) or in determining the load at which a relatively deep, narrow beam will buckle laterally (p. 159). Tests have been made to determine the modulus of rigidity in torsion for a few species used in aircraft, particularly spruce.

Sufficient data are available to indicate that the shear stresses at maximum torsional load, as calculated by the usual formulas, are approximately one-third greater than the shear stresses listed in table 8, which were obtained from block shear tests.

The effect of duration of stress on torsional strength is pronounced, the effect being greater on the proportional limit than on the maximum torsional strength. Approximately a 10-to-1 increase in the rate of applying a torsional load will increase the ultimate stress 10 percent and the proportional limit stress 20 percent.

When a piece of wood is twisted about a longitudinal axis parallel to the grain, its torsional rigidity depends upon two shear moduli. One is associated with stresses that cause slip along the grain in tangential planes and the other with stresses that produce a slippage along the grain in radial planes. These moduli do not differ greatly for most woods, and for practical design purposes a mean modulus, as determined by tests of pieces of square or circular section, may be used. The mean shear modulus, sometimes called modulus of rigidity, is approximately one-sixteenth of the modulus of elasticity along the grain.

A third shear modulus that does not come into play in torsion about an axis parallel to the grain is associated with stresses that tend to roll the wood fibers by each other in a direction at right angles to the grain. This shearing modulus is extremely low and of little importance in most design.

FATIGUE

The fatigue limit of wood (Kraemer, and Moore and Kommers), as determined by load reversal in rotational tests of beams having circular cross sections, is approximately one-third of the modulus of rupture, as determined in static tests, of beams having square cross sections. Sometimes the fatigue limit of wood beams with circular section is expressed as a ratio to the static modulus of rupture of beams also of circular section. Expressed in this way the ratio is less than one-third, since a beam of circular section has a form factor of 1.18 (p. 155). All such ratios assume that a generous fillet is left at any change in cross section; abrupt changes in section lower the fatigue limit markedly.

Recorded tests show that, for a stress just slightly greater than the fatigue limit, failure occurs after not more than 2,000,000 load reversals and for some species at less than a million reversals. Tests at stresses only slightly below the fatigue limit showed no failure after reversals ranging from 14,000,000 to 125,000,000.

SPECIFIC GRAVITY AND STRENGTH

The strength of wood is indicated by its density, which in the metric system is numerically equal to its specific gravity. The density of the actual wood substance, that is, the material of which the cell walls are composed, is substantially the same for all species; its value in the metric system is about 1.54. Therefore, all woods would be of the same specific gravity were it not for the fact that, because of variation in the size of the cell cavities and in thickness of cell wall, some have more wood substance than others. In addition, gums, resins, and extractives, when in considerable quantities, have an appreciable effect upon the specific gravity. The amount and the distribution of wood substance are the determining factors in the strength of a piece of wood.

In table 10 the relations between the specific gravity and various strength properties are expressed as equations (Markwardt) that are based on average results of strength tests on different species. This table shows that some strength properties, such as maximum crushing strength in compression parallel to the grain, vary directly as the first power of the specific gravity, while others, such as hardness, vary at a much more rapid rate.

TABLE 10.—*Specific gravity-strength relations of woods of different species* [1]

Property	Unit	Moisture condition	
		Green	Air-dry (12-percent moisture content)
Static bending:			
Fiber stress at proportional limit	Pounds per square inch	$10,200G^{1.25}$	$16,700G^{1.25}$
Modulus of rupture	do	$17,600G^{1.25}$	$25,700G^{1.25}$
Work to maximum load	Inch-pounds per cubic inch	$35.6G^{1.75}$	$32.4G^{1.75}$
Total work	do	$103G$ [2]	$72.7G$ [2]
Modulus of elasticity	1,000 pounds per square inch	2,360G	2,800G
Impact bending:			
Fiber stress at proportional limit	Pounds per square inch	$23,700G^{1.25}$	$31,200G^{1.25}$
Modulus of elasticity	1,000 pounds per square inch	2,940G	3,380G
Height of drop	Inches	$114G^{1.75}$	$94.6G^{1.75}$
Compression parallel to grain:			
Fiber stress at proportional limit	Pounds per square inch	5,250G	8,750G
Maximum crushing strength	do	6,730G	12,200G
Modulus of elasticity	1,000 pounds per square inch	2,910G	3,380G
Compression perpendicular to grain: Fiber stress at proportional limit.	Pounds per square inch	$3,000G^{2.25}$	$4,630G^{2.25}$
Hardness:			
End	Pounds [2]	$3,740G^{2.25}$	$4,800G^{2.25}$
Radial	do	$3,380G^{2.25}$	$3,720G^{2.25}$
Tangential	do	$3,460G^{2.25}$	$3,820G^{2.25}$

[1] The properties and values should be read as equations; for example, modulus of rupture for green material=$17,600G^{1.25}$, where G represents the specific gravity of oven-dry wood, based on the volume at the moisture condition indicated.

[2] The load required to embed a 0.444-inch ball to one-half its diameter.

When the equations of table 10 and the average specific gravity of a species are known, an estimate of its strength can be made. Tests (Newlin and Wilson, Dept. Bull. 676) on many of our native woods, however, show that actual average strength values for a species sometimes vary considerably from those calculated by the equations of the table. For instance, the true hickories, which are exceptional in shock resistance, test considerably higher in this property than indicated by their equation value, while some of the oaks are lower in shock resistance than indicated by their equation value. In general, however, a good estimate can be obtained. These instances are cited merely to show that equation values will not give exact strength figures.

Strengths of pieces of the same species vary by somewhat higher powers of the specific gravities than do average strength values of different species. For example, the maximum crushing strength in compression parallel to the grain of different species varies as the first power of the specific gravity, as shown in table 10, whereas for pieces of the same species the maximum crushing strength varies about as the one and one-fourth power of the specific gravity.

MOISTURE CONTENT AND STRENGTH

Wood increases in strength as it dries (Wilson, Tech. Bull. 282). With small, clear pieces, the strength in endwise compression, for example, is about twice as great for a moisture content of 12 percent as for green wood, and drying to about 5-percent moisture content will sometimes triple this property. Increase in strength does not begin, however, until the fiber-saturation point is reached. The fiber-saturation point, which is at approximately 30-percent moisture content, is reached when the free water in the cell cavities has been evaporated and the cell walls are still saturated.

Not all the strength properties of wood increase with a decrease in moisture content; in fact, those that represent toughness, or shock resistance, sometimes actually decrease as the wood dries. This is because dried wood will not bend so far as green wood before failure, although it will sustain a greater load, and because toughness is dependent upon both strength and pliability.

Frequently strength values are obtained for pieces at different moisture-content values, and the results are recorded as obtained. It is then necessary to adjust some values before a true comparison of results can be made.

A formula known as the "exponential formula," devised by the Forest Products Laboratory for strength adjustment by which fairly accurate values can be obtained, follows:

$$\text{Log } S_3 = \log S_1 + \left(\frac{M_1 - M_3}{M_1 - M_2}\right) \log \frac{S_2}{S_1}$$

where S_1 and M_1 are one pair of corresponding strength and moisture-content values as found from test, S_2 and M_2 are another pair, and S_3 is the strength value adjusted to the moisture content M_3.

If one strength value is for green material, the moisture content which must be used is that corresponding to the intersection of straight lines giving strength-moisture relations when strength values are plotted as ordinates and moisture-content values as abscissas on semilogarithmic paper (Wilson, Tech. Bull. 282). This value, which is somewhat lower than the fiber-saturation point, is designated as M_p. As previously stated, the strength undoubtely increases when the moisture is lowered below the fiber-saturation point but because of limitations in test procedure it is not practical to obtain a strength-moisture content relation starting at this point. Some experimentally determined values of M_p follow:

Species:	M_p (Percent)	Species (continued):	M_p (Percent)
Ash, white	24	Pine, longleaf	21
Birch, yellow	27	Pine, Norway	24
Chestnut	24	Redwood	21
Douglas fir	24	Spruce, red	27
Hemlock, western	28	Spruce, Sitka	27
Larch, western	28	Tamarack	24
Pine, loblolly	21		

For other species a value of 24 percent is assumed for M_p.

The exponential formula is not applicable to results of tests on wood in which there is a large variation in moisture content from one part of the cross section to another.

EXAMPLES OF APPLICATION OF FORMULA

Case 1.—Strength values S_1 and S_2 from matched specimens tested green, M_1, and air-dry, M_2, are known and the strength, S_3, at another air-dry moisture content, M_3, is desired. Then

$$\text{Log } S_3 = \log S_1 + \left(\frac{M_1 - M_3}{M_1 - M_2}\right) \log \frac{S_2}{S_1}$$

Example: Tests of matched specimens of Sitka spruce gave values of maximum crushing strength of 2,600 and 5,770 pounds per square inch, respectively, for green wood and wood at 8.9-percent moisture content. What is the strength value for a moisture content of 12 percent?

$$\text{Log } S_3 = \log 2{,}600 + \left(\frac{27 - 12}{27 - 8.9}\right) \log \frac{5{,}770}{2{,}600}$$

$S_3 = 5{,}030$ pounds per square inch.

Case 2.—The strength value at some air-dry moisture content, M_2, only is known and the strength value, S_3, at another air-dry moisture content, M_3, is desired. A good estimation of the true strength value S_3 can be obtained from the formula

$$\text{Log } S_3 = \log S_2 + (M_2 - M_3) \frac{\log \frac{S_{12}}{S_g}}{(M_p - 12)}$$

where S_g and S_{12} are values pertaining to green wood and wood at 12-percent moisture, respectively, as found in table 8 for the species in question.

Example: Some tests of eastern hemlock at 8-percent moisture content gave a value of modulus of rupture of 10,000 pounds per square inch. Estimate the value that would have been obtained had the tests been made at 13-percent moisture content.

$$\text{Log } S_3 = \log 10{,}000 + (8 - 13) \frac{\log \frac{8{,}900}{6{,}400}}{24 - 12}$$

$S_3 = 8{,}720$

(Since M_p has not been determined experimentally the value of 24 percent is taken.)

Case 3.—The strength value at some air-dry moisture content, M_2, only is known, and the strength value at another air-dry moisture content, M_3, is desired. The species is not included in table 8 as in case 2, and hence only an approximation of the true strength value can be obtained. The formula is

$$\text{Log } S_3 = \log S_2 + (M_2 - M_3) \frac{\log \frac{S_{12}}{S_g}}{24 - 12}$$

Average values of S_{12} over S_g, based on many different species and for use in the preceding formula are given in table 11.

Example: A piece of Central American mahogany at 9-percent moisture content tested 11,700 in modulus of rupture. Estimate the value for the same piece at 12-percent moisture.

$$\text{Log } S_3 = \log 11{,}700 + (9 - 12) \frac{\log 1.59}{24 - 12}$$

$S_3 = 10{,}420$

DURATION OF STRESS

Duration of stress is an important factor in determining the load a timber can safely carry. A beam loaded continuously for several years will break under a force about nine-sixteenths of that necessary to cause failure in a few minutes. If a beam is loaded quickly and the load released immediately, the beam will sustain a proportionately higher load; the increase is approximately 10 percent when the time of carrying the load is reduced to one-tenth of the previous time.

In compression parallel to the grain failure under long-time loading would be expected to occur at approximately the proportional limit stress as found in a test of short duration. The relation of proportional-limit strength to ultimate crushing strength parallel to the grain as obtained in a standard test of only a few minutes duration is 0.80 for the softwoods and 0.75 for the hardwoods.

TABLE 11.—*Strength of dry wood (12-percent moisture content) compared with strength of green wood—expressed as ratios*

Property	Hardwoods (average of 113 species)	Softwoods (average of 54 species)
Static bending:		
Fiber stress at proportional limit	1.80	1.81
Modulus of rupture	1.59	1.61
Modulus of elasticity	1.31	1.28
Work to proportional limit	2.49	2.56
Work to maximum load	1.05	1.13
Impact bending:		
Fiber stress at proportional limit	1.44	1.39
Work to proportional limit	1.68	1.59
Height of drop causing complete failure	.89	1.03
Compression parallel to the grain:		
Fiber stress at proportional limit	1.74	1.86
Maximum crushing strength	1.95	1.97
Compression perpendicular to the grain: Fiber stress at proportional limit	1.84	1.96
Hardness:		
End	1.55	1.67
Side	1.33	1.40
Shear parallel to the grain: Maximum shearing strength	1.43	1.37
Tension perpendicular to the grain: Maximum tensile strength	1.20	1.23

NATURAL CHARACTERISTICS INFLUENCING STRENGTH

KNOTS

As a knot appears on a sawed surface it is merely a section of the entire knot, its shape then depending upon the direction of the cut. When a knot is sawed through at right angles to its length a round knot results, when cut diagonally an oval knot results, and when sawed lengthwise a spike knot results.

Knots are further classified as intergrown or encased (pl. 1). As long as a limb remains alive, there is continuous growth at the junction of the limb and the trunk of the tree, and the resulting knot is called intergrown; after the limb has died, additional growth on the trunk encloses the dead limb and an encased knot results. The encased knot and the fibers of the trunk are not continuous, and consequently the distortion of the grain around the knot is less than for intergrown knots. Encased knots and knot holes are accompanied by less cross grain than are intergrown knots and hence have no more effect on the bending strength of lumber than do intergrown knots.

Knots do not decrease strength because of any inferiority in their quality, but because the grain of the piece is distorted in passing around them, because their own grain is at a large angle to the grain of the piece, and because of the checking that may occur in and around them in drying. The weakening effect of knots is greater on the tensile than on the compressive strength.

In structural beams the effect of knots on the bending strength is largely dependent upon the location of the knot (Garratt, Koehler,

and Newlin and Johnson). For example, in a beam simply supported, knots on the lower side are placed in tension, those on the upper side in compression, and those at or near the neutral axis in horizontal shear. On the lower side at the point of maximum stress a knot will have a marked effect on the maximum load a beam will sustain, while knots on the compression side are somewhat less serious, and in any location they have little effect on shear. The stiffness of beams is affected but little by knots.

In long columns, in which stiffness is the controlling factor, knots are not of importance. In short or intermediate columns the reduction in strength caused by knots is approximately proportional to the size of the knot, although large knots have a somewhat proportionately greater effect than small knots.

Knots in round material, such as poles and piling, have less effect on strength than knots in sawed timbers. Although the grain is irregular around knots in both forms its angle with the surface is less in naturally round than in sawed timbers. Furthermore, the round piece is often sufficiently enlarged at a knot to compensate, at least partially, for the effect of the irregular grain.

Observation of trees and poles bent or broken by windstorms or in felling or handling as well as in tests of round timber shows that first failure often occurs between, rather than at knots.

In order to maintain the maximum strength of round timbers, knots should not be trimmed below the natural surface of the piece; that is, such enlargements as exist at the knot should not be cut into.

CROSS GRAIN

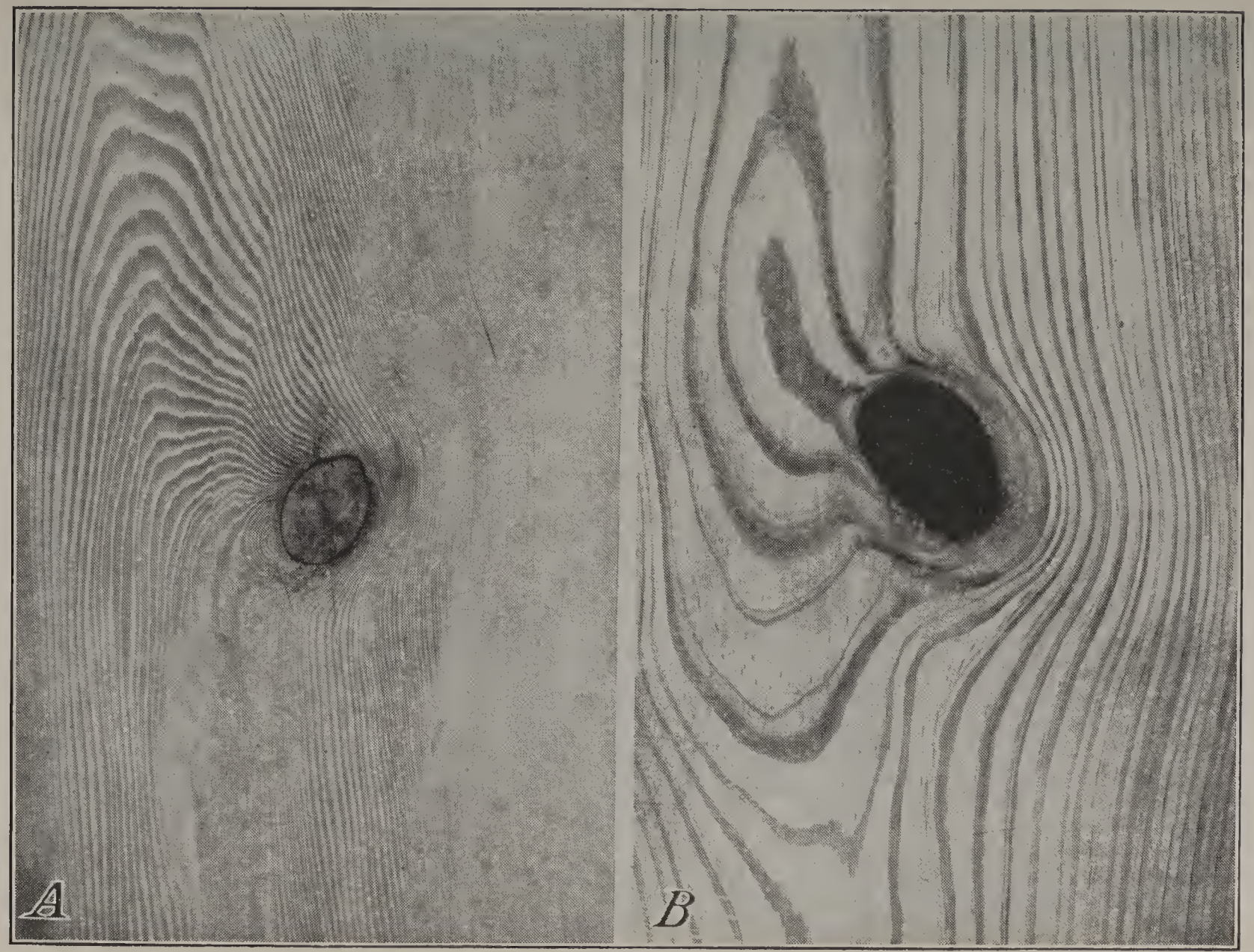
The fibers in a cross-grained piece of wood lie at an angle to the axis of the piece (Wilson, Jour. Forestry). The principal types of cross grain are spiral grain and diagonal grain (fig. 8). Other less important types are wavy, dipped, interlocked, and curly grain.

Spiral grain (pl. 2) is caused by the fibers growing in a winding or spiral course about the bole of a tree instead of in a vertical course.

Spiral grain is not always readily apparent in ordinary visual inspection. The best test for spiral grain is to split a piece at right angles to the annual rings. Another method of determining the presence of spiral grain is to note the alinement of pores, rays, and resin ducts on flat-grained faces. Checks on a flat-sawn surface also follow the fibers and when present indicate the direction of grain.

Diagonal grain results from sawing a piece of lumber at an angle other than parallel with the bark. One of the frequent causes is sawing a log having a pronounced taper parallel with the axis of the tree rather than parallel with the bark. It also occurs in sawing crooked or swelled-butt logs, and from careless sawing. Diagonal grain is easily detected by noting the slope of the annual rings on an edge-grain surface. Its presence but not the slope can be detected on a tangential surface by the numerous hyperbolas produced by the intersection of growth rings with the surface.

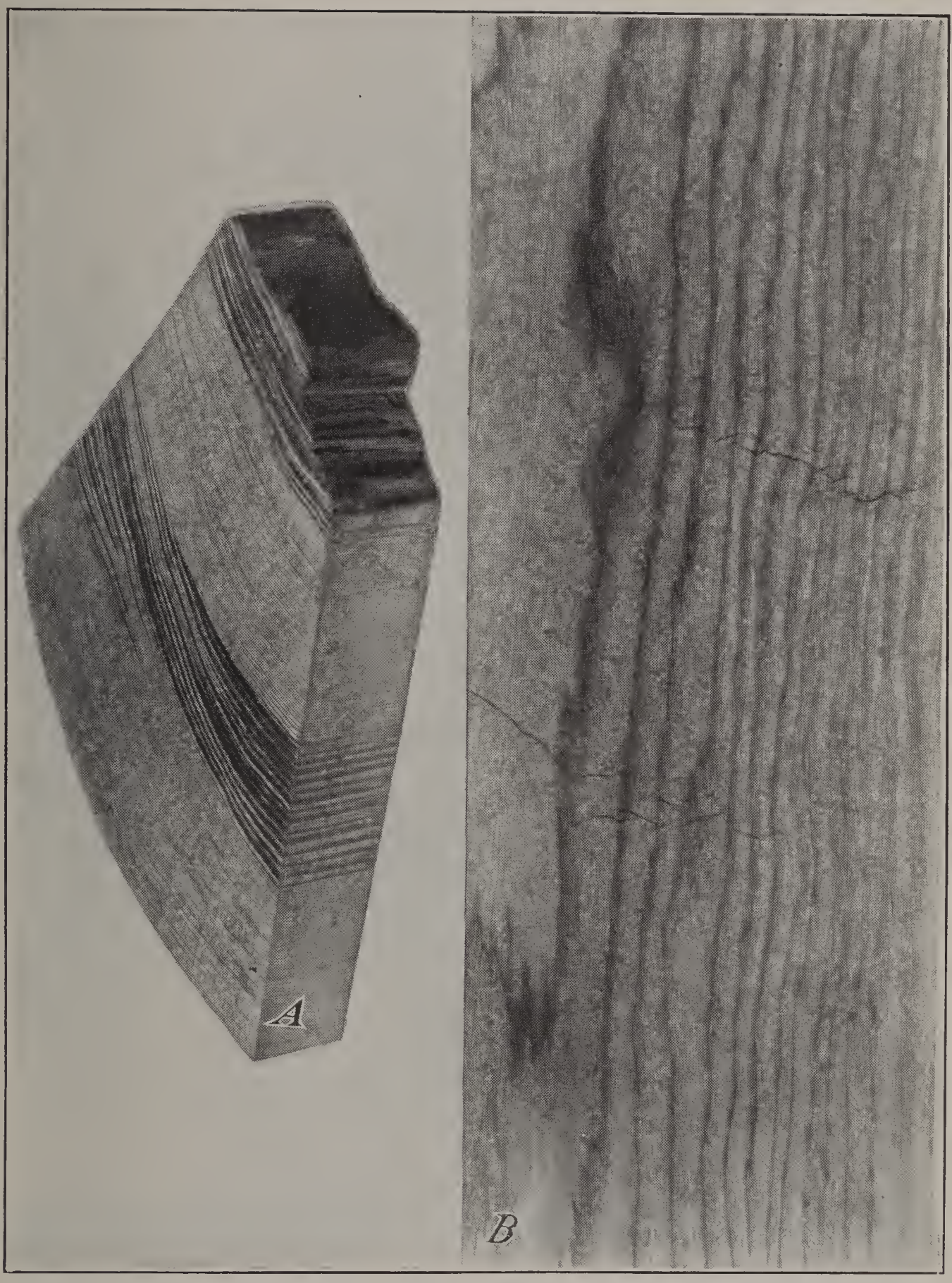
The slope of grain is usually expressed by the ratio between a 1-inch deviation of the grain from the edge or axis of a piece and the distance within which this deviation occurs. When a piece contains both spiral and diagonal grain the combined slope must be



A, Encased knot; B, intergrown knot.



Spiral-grained and straight-grained forest trees.



A, The darker areas shown are compression wood; B, Compression failure is shown by the dark irregular lines across the grain

considered rather than the greater of the two slopes. The combined slope is determined by taking the square root of the sum of the squares of the slopes of the two types of cross grain. For example, if these slopes are 1 in 18 and 1 in 12, the combined slope is

$$\sqrt{\left(\frac{1}{18}\right)^2+\left(\frac{1}{12}\right)^2}=\frac{1}{10}$$ or a slope of 1 in 10

Tests by the Forest Products Laboratory show the following: Compressive strength is but little affected until slopes of grain of 1 in 10 or greater are reached. Modulus of elasticity is more affected

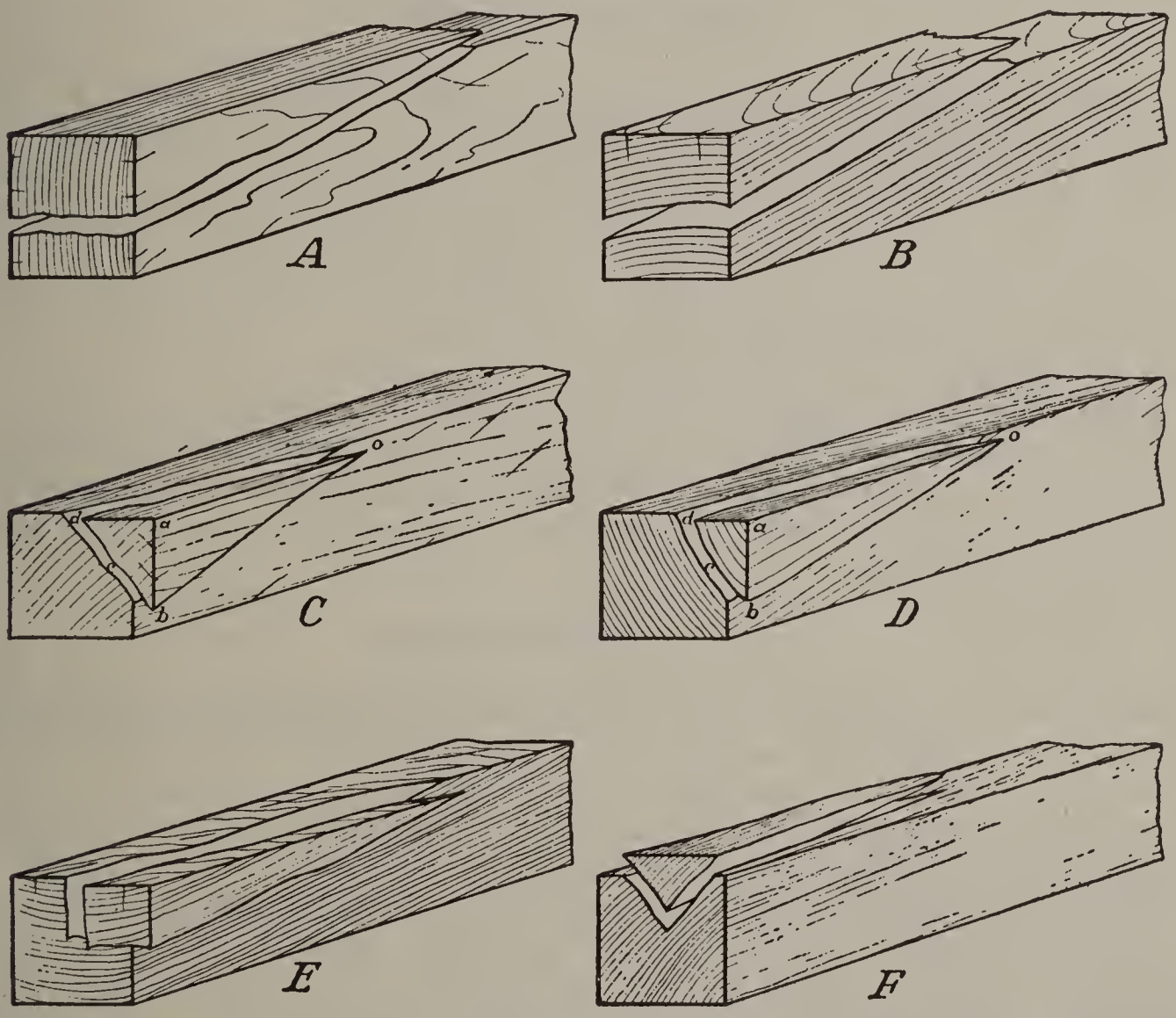


FIGURE 8.—Annual rings parallel to edge of cross section: *A*, Spiral grain; *B*, diagonal grain. Annual rings oblique to edge of cross section: *C*, Spiral grain; *D*, diagonal grain. Spiral and diagonal grain in combination: *E*, Annual rings parallel to edge of cross section; *F*, annual rings oblique to edge of cross section.

and begins to decrease appreciably at a slope of 1 in 15. Modulus of rupture decreases even more rapidly, becoming appreciable at a slope of 1 in 20. The most pronounced effect is on work to maximum load and maximum drop, both of which are measures of shock resistance; they become considerably deficient even at a slope of 1 in 25 and decrease rapidly as the slope of the grain becomes steeper.

COMPRESSION WOOD

Compression wood is an abnormal growth frequently occurring on the underside of leaning trees and limbs of softwood (coniferous) species. It is denser and harder than the normal wood, is characterized by wide annual growth rings usually eccentric, and includes

what appears to be an exceptional proportion of summer-wood growth (pl. 3, *A*). The contrast in color between spring wood and summer wood, however, is usually less in compression wood than in normal wood.

Compression wood has a high longitudinal shrinkage and is low in strength for its weight. When compression wood is present in the same board with normal wood, the unequal endwise shrinkage in the two parts causes bowing and crooking. Material containing compression wood is undesirable for substantially all lumber uses and should be rejected. Fortunately, only a small percentage of the lumber cut contains pronounced compression wood.

COMPRESSION FAILURES

Excessive bending of standing trees from wind or snow, felling trees across boulders, logs, or irregularities in the ground, or the rough handling of logs or lumber may produce excessive compression stresses along the grain which cause minute compression failures. In some instances such failures are visible on the surface of a board as minute ridges formed by the crumpling or buckling of the cells (pl. 3, *B*), although usually they appear only as white lines or may even be invisible to the naked eye.

The strength of a piece containing visible compression failures is seriously reduced, especially in tensile strength and shock resistance; such a piece may break suddenly along the compression failure when subjected to shock or tension, in which event the failure will have a brittle appearance.

MOLDS AND STAINING FUNGI

Molds and staining fungi (p. 249) do not ordinarily appreciably affect the strength of wood. Where molding or staining of wood is intensive the shock resistance may be greatly reduced, but even then such properties as compression parallel to the grain and bending strength are usually but little affected.

Although molds and stains themselves are usually not important as regards strength, conditions that favor the development of these fungi are likewise ideal for the growth of wood-destroying fungi (p. 249). Since decay even in is incipient stage may greatly reduce some strength properties, stained lumber should be regarded with suspicion when strength is an important factor.

DECAY

Unlike the sap-staining fungi, the decay-producing fungi cause a serious reduction in strength. Even apparently sound wood adjacent to obviously decayed parts may contain incipient decay that is decidedly weakening, especially in shock resistance.

Different wood-destroying fungi affect wood differently. The fungi that cause an easily recognized pitting of the wood, for example, may be less injurious to the strength than those that, in the early stages, give a slight discoloration of the wood as the only visible effect.

No method is known for estimating from the appearance of decayed wood the amount of reduction in its strength, and when

strength is an important consideration the safe procedure is to discard every piece that contains even a small amount of decay (p. 251).

INSECT DAMAGE

Insect damage may occur in standing trees, logs, and unseasoned or seasoned lumber. Damage in the standing tree is difficult to control but otherwise insect damage can be largely eliminated by proper control methods.

Insect holes are generally classified as pin holes, grub holes, and powder post (p. 254). The powder-post larvae by their irregular burrows may destroy most of the interior of a piece, while the surface shows only small holes, and the strength of the piece may be reduced virtually to zero.

No method is known for estimating from the appearance of insect-damaged wood the amount of reduction in strength, and when strength is an important consideration the safe procedure is to discard every piece that contains insect holes.

PITCH POCKETS

A pitch pocket is a well-defined opening extending parallel to the annual rings, substantially flat toward the pith and curved on the bark side, which contains more or less free resin. Pitch pockets are confined to the pines, spruces, Douglas fir, tamarack, and western larch.

The effect of pitch pockets on strength depends upon their number, size, and location in the piece; their effect on strength has often been overestimated. A large number of pitch pockets indicates a lack of bond between annual growth layers, and a piece containing them should be inspected for shakes.

MINERAL STREAKS

Maple, hickory, white ash, and a number of other species are often damaged by small holes made by sapsuckers. These holes or bird pecks are often placed in horizontal rows, sometimes encircling the tree, and a brown or a black discoloration known as a "mineral streak" has its origin at such holes. Holes for tapping maple trees are also a source of mineral streaks. The streaks are caused by oxidation and other chemical changes in the wood.

Bird pecks and mineral streaks are not important defects as regards strength, although they do impair the appearance of the wood. It is possible, however, that several bird pecks may occur in a row across the outer surface of a piece of wood that is to be bent, such as a buggy shaft or a handle, and then the holes would appreciably weaken the piece.

SEASONING DEFECTS

Seasoning defects (p. 204) are confined mostly to honeycombing and checking, with some discoloration when excessively high temperatures are used. A loss in strength accompanies seasoning defects, and some loss in strength, especially in shock resistance, may occur even when there are no visible defects. Even improperly seasoned wood, however, may be considerably higher in strength than material in the green condition, since properly seasoned wood

in the form of small, clear specimens may more than double in strength in seasoning from a green to a dry condition; the increase depends upon the strength property and the final moisture content. When proper methods are used in either of the common ways of drying wood, air seasoning and kiln drying, the effect on strength is the same; that is, proper kiln schedules will result in seasoned wood of as high quality as that resulting from careful air seasoning.

VALUE OF TIMBER FROM LIVE AND FROM DEAD TREES

Timber from trees killed by insects, blight, wind, or fire is undoubtedly as good for any structural purpose as that from live trees, provided additional injury from further insect attack, staining, decay, or seasoning defects has not occurred.

If a tree stands on the stump too long after its death, the sapwood is likely to become decayed or to be severely attacked by wood-boring insects, and in time the heartwood will be similarly affected. Such deterioration occurs also in logs that have been cut from live trees and improperly cared for subsequently. Because of variations in climatic and local weather conditions and in other factors that affect deterioration, the length of the period during which dead timber may stand or lie in the forest without serious deterioration varies. Tests on wood from trees that had stood as long as 15 years after being killed by fire demonstrated that this wood was sound and as strong as wood from live trees. Also logs of some of the more durable species have had thoroughly sound heartwood after lying on the ground in the forest for many years. On the other hand, decay may cause great loss of strength within a very brief time, both in trees standing dead on the stump and in logs that have been cut from live trees and allowed to lie on the ground. Consequently, the important consideration is not whether the trees from which timber products are cut are alive or dead, but whether the products themselves are free from decay or other defects that would render them unsuitable for use.

Decay, even when sufficiently advanced to affect seriously the strength of a piece of wood, is often difficult to detect. For this reason, and also because decay is present in timber from dead trees more frequently than in that cut from freshly felled live trees, timber from dead trees needs more careful inspection. Specifications for some timber products, notably poles and piling, often require that only live trees be used; this requirement, however, is difficult to enforce unless inspection is made in the forest, because wood cut from fire-killed, wind-fallen, or otherwise naturally killed trees before weathering, seasoning, discoloration, decay, insect attack, or similar change has occurred cannot be distinguished from wood taken from live trees. Many specifications omit the live-tree requirement, depending entirely upon inspection to determine the suitability of the timber for use.

RESIN

Resin is formed in some of the conifers, especially the southern yellow pines. Resin is common in amounts up to 6 percent of the dry weight of the wood and pieces with a resin content up to 50 percent are sometimes found.

Tests at the Forest Products Laboratory on southern yellow pine indicate that resin will slightly increase some strength properties, but the effect is too small to be of any particular significance; that is, any additional strength resulting from the presence of resin is very small as compared to that which would normally result from an equal additional weight of wood substance. An excessive amount of resin is sometimes associated with an injury that may have greatly reduced the strength.

TURPENTINING

Some species of southern yellow pine trees are frequently tapped for turpentine, and if the turpentining is properly handled the trees are not unduly damaged for lumber purposes. Comparative tests on mature turpentined and unturpentined trees have shown that (1) turpentined timber is as strong as unturpentined timber of the same weight, (2) the weight and shrinkage of wood are not affected by turpentining, (3) practically speaking, properly turpentined trees contain neither more nor less resin than unturpentined trees.

EXTRACTIVES

Extractives, the portion of wood that will dissolve when a piece is placed in an inert solvent, occur in many species and are especially abundant in redwood, western red cedar, and black locust (Luxford). The three species mentioned are also relatively high in certain strength properties for the amount of wood substance they contain and tests at the Forest Products Laboratory have shown that the presence of extractives is probably accountable. The extent to which extractives affect the strength is apparently dependent upon the amount and nature of extractives, the moisture condition of the piece, and the mechanical property under consideration. Of the properties examined, maximum crushing strength in compression parallel with the grain showed the greatest increase from the infiltration of extractives in the change of sapwood into heartwood, the modulus of rupture came next, and shock resistance showed the least. In fact, under some conditions, shock resistance appears to be actually lowered by extractives. That the extractives found in different species may affect the strength differently is indicated by the fact that they change the strength of western red cedar less than the strength of black locust, although black locust has a smaller percentage of extractives (Luxford).

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GRADES AND SIZES OF LUMBER

A large tree when sawed into lumber yields boards of widely varying quality. Lumber grades divide the product of the tree into several segregations each having a relatively narrow range in quality which enables each user to buy the quality that best suits his use and purpose.

Except as noted later, the grade of a piece of lumber is based on the number, character, and location of such features as knots, pitch pockets, and the like, which are commonly referred to as defects and are defined as "any irregularity occurring in or on wood that may lower some of its strength, durability, or utility values." Among the more common of such features are knots, checks, pitch pockets, shake, and stain, some of which are a natural part of the tree. The best grades are free or practically free from these features while the others comprising the great bulk of lumber contain fairly numerous knots and other natural growth characteristics. These characteristics, however, do not prevent such lumber from giving satisfaction for many wide-spread uses.

Following is a list of the principal lumber manufacturers' associations and the woods graded under the rules of each association:

PRINCIPAL LUMBER MANUFACTURERS' ASSOCIATIONS AND WOODS GRADED UNDER THE RULES OF EACH ASSOCIATION

Name and address	Woods covered by grading rules
Hardwood Dimension Manufacturers' Association, Memphis, Tenn	Hardwoods (dimension or cut stock).
Hardwood Interior Trim Manufacturers' Association, 63 South Third Street, Memphis, Tenn	Hardwood (trim).
Hardwood Maufacturers' Institute, Memphis, Tenn	No grading rules.
Maple Flooring Manufacturers' Association, 332 South Michigan Avenue, Chicago, Ill	Maple (northern hard),[7] beech, birch (flooring).
National Hardwood Lumber Association, 2408 Buckingham Building, Chicago, Ill	Hardwoods, cypress,[8] aromatic red cedar.[9]
National Oak Flooring Manufacturers' Association, 604 Dermon Building, Memphis, Tenn	Oak (flooring).
California Redwood Association, 405 Montgomery Street, San Francisco, Calif	Redwood.
Northeastern Lumber Manufacturers' Association, Chanin Building, New York, N. Y	Balsam fir, northern white pine, eastern hemlock, and eastern spruce.

[7] Forest Service name, hard maple.
[8] Forest Service name, southern cypress.
[9] Forest Service name, eastern red cedar.

Name and address	Woods covered by grading rules
Northern Hemlock & Hardwood Manufacturers' Association, Oshkosh, Wis.	Eastern hemlock, tamarack, northern white cedar.
Northern Pine Manufacturers' Association, Lumber Exchange Building, Minneapolis, Minn.	Northern white pine, Norway pine, eastern spruce, and jack pine.
Southern Cypress Manufacturers' Association, Barnett National Bank Building, Jacksonville, Fla.	Southern cypress (upland and tidewater types).[8]
Southern Pine Association, New Orleans, La.	Longleaf and shortleaf southern yellow pine.
West Coast Lumbermen's Association, Stuart Building, Seattle, Wash.	Douglas fir (coast region), west coast hemlock,[10] Sitka spruce, western red cedar, Port Orford cedar.
Western Pine Association, Yeon Building, Portland, Oreg.	Ponderosa pine, Idaho white pine,[11] sugar pine, western larch, Douglas fir ("Inland Empire" and California), white fir, Engelmann spruce, incense cedar, and western red cedar.
Red Cedar Shingle Bureau, Stuart Building, Seattle, Wash.	Western red cedar (shingles).

[8] Forest Service name, southern cypress.
[10] Forest Service name, western hemlock.
[11] Forest Service name, western white pine.

HARDWOOD LUMBER GRADING

HARDWOOD LUMBER (ALL SPECIES)

The rules which are considered standard in grading hardwood lumber in the United States are those adopted by the National Hardwood Lumber Association.[12] [13] In these rules the grade of a piece of hardwood lumber is determined by the proportion of the piece that can be cut into a certain number of smaller pieces of material clear on one side and not less than a certain size. In other words, the grade classification is based upon the amount of clear usable lumber in the piece rather than upon the number or size of the features that occur in the cutting. This clear material, commonly termed "clear cuttings", must have one face clear and the reverse face sound, which means free from rot, heart center, shake, and other features that materially impair the strength of the cutting. Some grades require only that cuttings be sound.

The highest grade of hardwood lumber is termed "Firsts" and the next grade "Seconds." Firsts and Seconds, or, as they are generally written, "FAS", practically always are combined in one grade. The third grade is termed "Selects", followed by No. 1 Common, No. 2 Common, Sound Wormy, No. 3A Common, and No. 3B Common.

The hardwood grading provisions described herein, although not incorporated in American lumber standards, have been accepted by

[12] This association publishes a booklet which contains detailed grading rules for various hardwood products, such as lumber, flooring, and vehicle stock. The association maintains bonded lumber inspectors in various hardwood producing and consuming centers who issue inspection certificates on shipments. The correctness of the grades as shown on these certificates is guaranteed by the association.
[13] For further information, the references at the end of this section should be consulted.

the central committee on lumber standards as being in accord with its published recommendations for both basic grades and species nomenclature.

A brief summary of the hardwood grades is given below. This summary should not be regarded as a complete set of grading rules, as there are numerous details, exceptions, and special rules for certain species that are not included. The complete official rules of the association should be followed as the only full description of existing grades (Hardwood Interior Trim Manufacturers' Association, Maple Flooring Manufacturers' Association, National Hardwood Lumber Association, and National Oak Flooring Manufacturers' Association). The summary is intended only as a preliminary guide in distinguishing between the general qualities to be expected under the various grades.

SUMMARY OF STANDARD GRADES OF THE NATIONAL HARDWOOD LUMBER ASSOCIATION

Woods Included [14]

Alder, red
Ash
Aspen
Basswood
Beech
Birch
Boxelder
Buckeye
Butternut
Cedar, red
Cherry
Chestnut
Cottonwood
Cypress
Elm:
- Rock (or cork)
- Soft

Gum:
- Black
- Red and sap
- Tupelo

Hackberry
Hickory
Locust
Magnolia
Mahogany:
- African
- Cuban and San Dominican
- Mexican
- Philippine

Maple
- Hard (or sugar)
- Soft

Oak:
- Red
- White

Pecan
Poplar
Sycamore
Walnut
Willow

Standard Lengths (Feet)

Standard lengths are 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, and 16 feet, but not over 50 percent of odd lengths will be admitted.

Standard Thicknesses (Inches)

Standard thicknesses for hardwood lumber are given in table 12.

Table 12.—*Standard thicknesses for hardwood lumber*

Rough (inches)	Surfaced 1 side (S1S)	Surfaced 2 sides (S2S)	Rough (inches)	Surfaced 1 side (S1S)	Surfaced 2 sides (S2S)
	Inches	*Inches*		*Inches*	*Inches*
3/8	1/4	3/16	2 1/2	2 5/16	2 1/4
1/2	3/8	5/16	3	2 13/16	2 3/4
5/8	1/2	7/16	3 1/2	3 5/16	3 1/4
3/4	5/8	9/16	4	3 13/16	3 3/4
1	7/8	13/16	4 1/2	(1)	(1)
1 1/4	1 1/8	1 1/16	5	(1)	(1)
1 1/2	1 3/8	1 5/16	5 1/2	(1)	(1)
2	1 13/16	1 3/4	6	(1)	(1)

[1] Finished size not specified in rules. Stock usually made in small quantities or on special order.

[14] Two of the woods included, namely, cedar (eastern red cedar) and cypress (southern cypress), are not hardwoods. Cypress lumber has a different set of grading rules from those used for the hardwoods. All cypress rules are originated by the Southern Cypress Manufacturers' Association and are either used verbatim or with minor changes by the National Hardwood Lumber Association.

Description of Standard Hardwood Grades

A description of the standard hardwood grades is given in table 13.

Table 13.—*Standard hardwood grades* [1]

Grade, and lengths allowed (feet)	Widths allowed	Surface measure of pieces (square feet)	Percentage of each piece that must work into clear-face cuttings	Maximum cuttings allowed	Minimum size of cuttings required
	Inches		*Percent*	*Number*	
Firsts: [2]					
8 to 16 (will admit 25 percent of 8- to 11-foot, half of which may be 8- and 9-foot).	6+	4 to 9	91⅔	1	4 inches by 5 feet, or 3 inches by 7 feet.
		10 to 14	91⅔	2	
		15+	91⅔	3	
Seconds: [2]					
8 to 16 (will admit 25 percent of 8- to 11-foot, half of which may be 8- and 9-foot).	6+	4 and 5	83⅓	1	Do.
		6 and 7	83⅓	1	
		6 and 7	91⅔	2	
		8 to 11	83⅓	2	
		8 to 11	91⅔	3	
		12 to 15	83⅓	3	
		12 to 15	91⅔	4	
		16+	83⅓	4	
Selects:					
6 to 16 (will admit 30 percent of 6- to 11-foot, one-sixth of which may be 6- and 7-foot).	4+	2 and 3	91⅔	1	Do.
		4+	[3]		
No. 1 Common:					
4 to 16 (will admit 10 percent of 4- to 7-foot, half of which may be 4- and 5-foot).	3+	1	100	0	4 inches by 2 feet, or 3 inches by 3 feet.
		2	75	1	
		3 and 4	66⅔	1	
		3 and 4	75	2	
		5 to 7	66⅔	2	
		5 to 7	75	3	
		8 to 10	66⅔	3	
		11 to 13	66⅔	4	
		14+	66⅔	5	
No. 2 Common:					
4 to 16 (will admit 30 percent of 4- to 7-foot, one third of which may be 4- and 5-foot).	3+	1	66⅔	1	3 inches by 2 feet.
		2 and 3	50	1	
		2 and 3	66⅔	2	
		4 and 5	50	2	
		4 and 5	66⅔	3	
		6 and 7	50	3	
		6 and 7	66⅔	4	
		8 and 9	50	4	
		10 and 11	50	5	
		12 and 13	50	6	
		14+	50	7	
Sound Wormy:					
4 to 16 (will admit 10 percent of 4- to 7-foot, half of which may be 4- and 5-foot).	3+	----------	[4]	----------	
No. 3A Common:					
4 to 16 (will admit 50 percent of 4- to 7-foot, half of which may be 4- and 5-foot).	3+	1+	[5] 33⅓	[6]	3 inches by 2 feet.
No. 3B Common:					
4 to 16 (will admit 50 percent of 4- to 7-foot, half of which may be 4- and 5-foot).	3+	1+	[7] 25	[6]	1½ inches wide and containing at least 36 square inches.

[1] Inspection to be made on the poorer side of the piece, except in selects.
[2] Firsts and Seconds are combined as 1 grade (FAS). The percentage of Firsts required in the combined grade varies from 20 to 40 percent, depending on the species.
[3] Same as seconds.
[4] Cutting requirements same as in No. 1 Common, except that worm holes, bird pecks, sound stain, sound knots not over ¾ inch in diameter, and other similar sound defects will be admitted in the cuttings.
[5] This grade also admits pieces which grade not below No. 2 Common on the good face and have the reverse face sound.
[6] Not specified.
[7] The cuttings must be sound; clear face not required.

The highest grade, Firsts, calls for pieces which will allow 91⅔ percent of their surface measure to be cut into clear-face material; that is, not more than 8⅓ percent of each piece can be wasted in

making the required cuttings. In the grade of Seconds 83⅓ percent of the surface measure of the pieces must yield clear-face cuttings.[15] Both Firsts and Seconds require pieces not less than 6 inches wide and 8 feet long. In the grade Selects the minimum width is 4 inches and the minimum length 6 feet. Both Firsts and Seconds and the face side of Selects must in addition to cutting requirements also meet specified requirements as to the limitation of knots, holes, and the like. The cutting requirements of Selects are 91⅔ percent clear face in pieces with 2 and 3 surface feet. In larger pieces the cutting requirements are the same as for Seconds on the face side. The reverse side of the cuttings in Selects must be sound or the reverse side of the piece not below No. 1 Common. The next two grades, No. 1 Common and No. 2 Common, call for material not less than 3 inches wide and 4 feet long and require [16] 66⅔ percent and 50 percent clear-face cuttings, respectively. The minimum size of cuttings in these two grades is reduced from 4 inches by 5 feet or 3 inches by 7 feet in Firsts, Seconds, and Selects to 4 inches by 2 feet or 3 inches by 3 feet.

In the grade of Sound Wormy the requirements are the same as in No. 1 Common except that worm holes and similar features are allowed in the cuttings. The grade of 3A Common admits pieces that will furnish 33⅓ percent clear face in cuttings not less than 3 inches wide and 2 feet long. This grade will also admit pieces that grade not below No. 2 Common on the good face and have the reverse face of the cutting sound. The lowest grade, No. 3B Common, allows pieces that will cut 25 percent in sound material not less than 1½ inches wide and having at least 36 square inches surface measure.

HARDWOOD FLOORING

Hardwood flooring is generally graded under the rules of the Maple Flooring Manufacturers' Association and the rules of the National Oak Flooring Manufacturers' Association. The National Hardwood Lumber Association has adopted the rules of the latter association. Tongue-and-groove and end-matched hardwood flooring is commonly furnished. Square-edge and square-end strip flooring is also available, as well as parquetry flooring suitable for laying on a mastic base or on an ordinary subfloor.

The Maple Flooring Manufacturers' Association grading rules cover flooring manufactured from sugar maple (hard maple), beech, and birch.

Each species has the three grades designated as First grade, Second grade, and Third grade. There are also three special grades—White Clear Northern Hard Maple, Red Clear Northern Beech, and Red Clear Northern Birch, which are made up of special stock selected for uniformity of color. First grade flooring must have one face practically free from all defects. Variations in

[15] Boards 6 to 15 feet surface measure will admit of one additional cutting to yield 91⅔ percent clear face.

[16] Exceptions in No. 1 Common are pieces with 1 foot surface meausre and 2 feet surface measure, which require 100 percent clear face and 75 percent clear face, respectively, and in No. 2 Common pieces with 1 foot surface measure, which require 66 percent clear face.

the natural color of the wood are allowed. Second grade flooring will admit tight, sound knots and slight imperfections but must lay without waste. Third grade flooring has no restrictions as to imperfections in the grain but must be of such a character that it can be properly laid and will give a good serviceable floor. The standard thickness of maple, beech, and birch flooring is twenty-five thirty-seconds inch. Faces or widths are 1½, 2, 2¼, and 3¼ inches. Standard lengths are from 2 to 16 feet in First grade flooring and from 1 to 16 feet in Second grade and Third grade flooring.

The grading rules of the National Oak Flooring Manufacturers' Association cover quarter-sawed and plain-sawed oak flooring. Quarter-sawed flooring has three grades—Clear, Sap Clear, and Select. Plain-sawed flooring has four grades—Clear, Select, No. 1 Common, and No. 2 Common. The Clear grade in both plain- and quarter-sawed flooring must have one face practically free from surface imperfections except three-eighths inch of bright sap. Color is not considered in any grade. Sap Clear quarter-sawed flooring must have one face practically clear but will admit unlimited bright sap. Select flooring (plain- or quarter-sawed) may contain sap and will admit a few features such as pinworm holes and small tight knots. No. 1 Common plain-sawed flooring must contain material that will make a sound floor without cutting. No. 2 Common may contain grain and surface imperfections of all kinds but must be usable with some cutting in laying a serviceable floor. Standard thicknesses of oak flooring are $\frac{13}{16}$, ½, and ⅜-inch. Standard widths are 1½, 2, and 2¼ inches. Lengths in the upper grades are 2 feet and up, with a required average of 5 feet in a shipment. In the lower grades lengths are 1¼ feet and up, with a required average of 2½ or 3 feet.

HARDWOOD INTERIOR TRIM

Hardwood interior trim and molding are generally graded under the rules of the Hardwood Interior Trim Manufacturers' Association. These rules have been adopted by the National Hardwood Lumber Association. The rules have only a single grade in all species designated as grade A. This grade provides for practically clear-face trim except for slight imperfections that vary with the species and are allowed in not more than 10 percent of a shipment. Kiln-dried material is required with a moisture content of not to exceed 10 percent when shipped from the mill. The design and sizes of trim and molding conform to American lumber standards.

HARDWOOD DIMENSION STOCK

Hardwood dimension stock, such as is used by furniture, cabinet, and automobile-body manufacturers, is generally graded under the rules of the Hardwood Dimension Manufacturers' Association. These rules apply primarily to dimension stock cut from kiln-dried rough lumber and cover four classes of material—kiln-dried glued dimension, solid dimension flat stock, solid dimension squares, and automobile dimension. Each class may be rough, semifinished, or

finished. Glued dimension has five grades—Clear Two Faces, Clear One Face, Paint, No. 1 Core, and No. 2 Core. Solid dimension flat stock and solid dimension squares have the same three grades—Clear, Select, and Sound. Automobile dimension has four grades—Clear, Knot Free, No. 1 Sound, and No. 2 Sound.

SOFTWOOD LUMBER GRADING

Softwood lumber, unlike hardwood lumber, is graded under a number of different association rules. Not only are the different kinds of softwoods graded under different rules, but the same softwoods in a number of cases are graded under different association rules.

The first softwood rules were comparatively simple because the sawmills marketed their lumber locally and grades had only local significance; but as the earlier sources of timber became depleted and newer sources were developed and transported to more distant points, each producing region continued to establish its own grading rules with the result that lumber from different regions differed in sizes, grade names, and most important of all in grade quality. When several different species graded under different rules came into keen competition in the chief consuming areas confusion and dissatisfaction were inevitable.

In order to eliminate unnecessary differences in the grading rules of the various softwood lumber manufacturers' associations and to secure the improvement and simplification of these rules, American lumber standards were formulated. These standards were the result of a number of conferences organized by the United States Department of Commerce and attended by representatives of lumber manufacturers, distributors, wholesalers, retailers, engineers, architects, and contractors (Sweet). The United States Department of Agriculture, through special studies by the Forest Products Laboratory, contributed part of the information that was needed in the formulation of the standards. The standards themselves are issued in pamphlet form as simplified practice recommendations of the Bureau of Standards.

American lumber standards have been adopted in principle by the leading softwood lumber associations (California Redwood Association, Southern Cypress Manufacturers' Association, Southern Pine Association, West Coast Lumberman's Association, and Western Pine Association).

NOMENCLATURE OF COMMERCIAL SOFTWOODS

The names of lumber adopted by the trade as American lumber standards are not always identical with the names adopted as official by the Forest Service. Where the names are not identical some confusion may result. Table 14 has therefore been prepared to show the American lumber standards name corresponding to the Forest Service name used in this handbook. Other names sometimes used locally but not in contracts and botanical names are also shown.

TABLE 14.—*Nomenclature of commercial softwoods*

Official Forest Service name used in this handbook	Name adopted as standard under American lumber standards	Other names sometimes used	Botanical name
CEDARS AND JUNIPERS			
Alaska cedar	Alaska cedar	Yellow cedar, Sitka cypress, yellow cypress.	*Chamaecyparis nootkatensis.*
Alligator juniper	Western juniper	Juniper	*Juniperus pachyphloea.*
Eastern red cedar	Eastern red cedar	Red cedar, cedar, juniper	*Juniperus virginiaina.*
Incense cedar	Incense cedar	Cedar, white cedar	*Libocedrus decurrens.*
Northern white cedar	Northern white cedar	Arborvitae, cedar, swamp cedar, white cedar.	*Thuja occidentalis.*
Port Orford cedar	Port Orford cedar	Lawson's cypress, Oregon cedar, white cedar.	*Chamaecyparis lawsoniana.*
Rocky Mountain red cedar.	Western juniper	Juniper	*Juniperus scopulorum.*
Southern white cedar	Southern white cedar	White cedar, swamp cedar, juniper.	*Chamaecyparis thyoides.*
Utah juniper	Western juniper	Juniper, white cedar	*Juniperus utahensis.*
Western juniper	do	Juniper, cedar	*Juniperus occidentalis.*
Western red cedar	Western red cedar	Red cedar, cedar, western cedar.	*Thuja plicata.*
CYPRESS			
Southern cypress	Red cypress (coast type), yellow cypress (inland type), white cypress (inland type).	Cypress, tidewater red cypress, Gulf coast red cypress, Louisiana red cypress, bald cypress, red cypress, black cypress.	*Taxodium distichum.*
DOUGLAS FIR			
Douglas fir	Douglas fir (Coast region), Douglas fir (Inland empire and California), Douglas fir (Rocky Mountain region).	Red fir, Oregon fir, Douglas spruce, yellow fir, Puget Sound pine, Oregon pine.	*Pseudotsuga taxifolia.*
THE TRUE FIRS			
Alpine fir	Alpine fir	Balsam, white fir	*Abies lasiocarpa.*
Balsam fir	Balsam fir	Balsam, eastern fir	*Abies balsamea.*
Southern balsam fir	do	do	*Abies fraseri.*
California red fir	Golden fir	Red fir	*Abies magnifica.*
Noble fir	Noble fir	do	*Abies nobilis.*
Silver fir	Silver fir	Red fir, white fir, fir	*Abies amabilis.*
White fir	White fir	Colorado white fir	*Abies concolor.*
Lowland white fir	do	Yellow fir	*Abies grandis.*
HEMLOCKS			
Eastern hemlock	Eastern hemlock	Hemlock, hemlock spruce, spruce pine.	*Tsuga canadensis.*
Mountain hemlock	Mountain hemlock	Weeping spruce, Alpine spruce, hemlock spruce.	*Tsuga mertensiana.*
Western hemlock	West coast hemlock	Hemlock, hemlock spruce, Pacific hemlock, Alaska pine.	*Tsuga heterophylla.*
LARCH			
Western larch	Western larch	Tamarack, larch	*Larix occidentalis.*

TABLE 14.—*Nomenclature of commercial softwoods*—Continued

PINES

Official Forest Service name used in this handbook	Name adopted as standard under American lumber standards	Other names sometimes used	Botanical name
Western white pine	Idaho white pine	White pine, soft pine	*Pinus monticola.*
Jack pine	Jack pine	Scrub pine	*Pinus banksiana.*
Loblolly pine	Loblolly pine [1]	Old-field pine, slash pine, shortleaf pine, Virginia pine, sap pine, yellow pine, North Carolina pine.	*Pinus taeda.*
Lodgepole pine	Lodgepole pine	Scrubpine, spruce pine	*Pinus contorta.*
Longleaf pine	Longleaf pine [1]	Southern pine, yellow pine, hard pine, Georgia pine, pitch pine, heart pine, fat pine, southern yellow pine.	*Pinus palustris.*
Northern white pine	Northern white pine	White pine, cork pine, soft pine, northern pine, pumpkin pine, eastern white pine.	*Pinus strobus.*
Norway pine	Norway pine	Red pine, hard pine, northern pine.	*Pinus resinosa.*
Pond pine	Pond pine	Marsh pine, loblolly pine, spruce pine, bull pine.	*Pinus rigida serotina.*
Ponderosa pine	Ponderosa pine	Western yellow pine, bull pine, Arizona white pine, western soft pine, western pine.	*Pinus ponderosa.*
Shortleaf pine	Shortleaf pine [1]	Yellow pine, spruce pine, oldfield pine, Arkansas solft pine, North Carolina pine.	*Pinus echinata.*
Slash pine	Slash pine [1]	Swamp pine, pitch pine	*Pinus caribaca.*
Sugar pine	Sugar pine	Big pine	*Pinus lambertiana.*

REDWOOD

Redwood	Redwood	Sequoia, coast redwood	*Sequoia sempervirens.*

SPRUCES

Red spruce	Eastern spruce	Red spruce	*Picea rubra.*
White spruce	do	White spruce	*Picea glauca.*
Black spruce	do	Black spruce	*Picea mariana.*
Engelmann spruce	Engelmann spruce	White spruce, silver spruce, balsam, mountain spruce.	*Picea engelmannii.*
Sitka spruce	Sitka spruce	Spruce, tideland spruce, western spruce, yellow spruce, silver spruce.	*Picea sitchensis.*

TAMARACK

Tamarack	Tamarack	Larch, hackmatack, red larch, black larch.	*Larix laricina.*

YEW

Pacific yew	Pacific yew	Yew, western yew, mountain mahogany.	*Taxus brevifolia.*

[1] American lumber standards name "Arkansas pine" includes loblolly pine and shortleaf pine; "North Carolina pine" includes loblolly pine, shortleaf pine, and Virginia pine; "Southern pine" includes longleaf pine, shortleaf pine, loblolly pine, slash pine, pond pine, and pitch pine.

GENERAL CLASSIFICATION OF SOFTWOOD LUMBER

Softwood lumber is divided into three main classes—yard lumber, structural material (often referred to under the general term "timbers"), and factory and shop lumber. The following classification of softwood lumber gives the grade names used by lumber manufacturers' associations for the various classes of material under the American lumber-standards system.

				Grades
Softwood lumber (this classification applies to rough or dressed lumber; sizes given are nominal)	Yard lumber (lumber less than 5 inches thick, intended for general building purposes; grading based on use of the entire piece)	Finish (less than 3 inches thick and 12 inches and under in width)		A select B select C select D select
		Boards (less than 2 inches thick and 8 inches or over in width). Strips (under 8 inches in width)		No. 1 boards No. 2 boards No. 3 boards No. 4 boards No. 5 boards
		Dimension (2 inches and under 5 inches thick and of any width)	Planks (2 inches and under 4 inches thick and 8 inches and over wide)	No. 1 dimension No. 2 dimension No. 3 dimension
			Scantling (2 inches and under 5 inches thick and under 8 inches wide)	No. 1 dimension No. 2 dimension No. 3 dimension
	Structural material (lumber 5 inches or over in thickness and width, except joist and plank; grading based on strength and on use of entire piece)		Heavy joists (4 inches thick and 8 inches or over wide)	No. 1 dimension No. 2 dimension No. 3 dimension
		Joist and plank (2 inches to 4 inches thick and 4 inches and over wide)		
		Beams and stringers (5 inches and over thick and 8 inches and over wide)		
		Posts and timbers (6 by 6 inches and larger)		
	Factory and shop (grading based on area of piece suitable for cuttings of certain size and quality)	Factory plank graded for door, sash, and other cuttings 1 inch to 4 inches thick and 5 inches and over wide	Factory clears upper grades	Nos. 1 and 2 clear factory No. 3 clear factory
			Shop lower grades	No. 1 shop No. 2 shop No. 3 shop
		Shop lumber graded for general cut up purposes	1 inch thick (northern and western pine, and Pacific coast woods)	Select Shop
			All thicknesses (cypress, redwood, and North Carolina pine)	Tank and boat stock, firsts and seconds, selects, No. 1 shop No. 2 shop, box

YARD LUMBER—SIZE STANDARDS

Standard lengths are multiples of 2 feet except for the following odd lengths which are allowed:

	Feet
2 by 4 inches, 6 by 8 inches	9 and 11.
2 by 8 inches	13.
2 by 10 inches	13 and 15.

The thickness and widths of various yard-lumber products in three conditions—rough green, rough dry, and dressed—are given in table 15. In commercial practice the dressed dimensions are considered minima, and some association rules provide for thicker and wider sizes than American lumber standards.

YARD LUMBER—GRADE STANDARDS

Ordinary building lumber is graded by lumber manufacturers' associations as finish items, select A, B, C, and D.; boards no. 1, no. 2, no. 3, no. 4, and no. 5; and dimension, no. 1 dimension, no. 2 dimen-

sion, and no. 3 dimension. The general requirements of these grades as used by lumber manufacturers' associations under the American lumber standards system are as follows:

- Total products of a typical log arranged in series according to quality as determined by appearance
  - Finish items [17] (lumber of good appearance and finishing)
    - Suitable for natural finishes
      - Grade A (practically free from defects)
      - Grade B (allows a few small defects or blemishes)
    - Suitable for paint finishes
      - Grade C (allows a limited number of small defects or blemishes that can be covered with paint)
      - Grade D (allows any number of defects or blemishes which do not detract from the appearance of the finish expecially when painted)
  - Boards [17] (lumber containing defects or blemishes which detract from the appearance of the finish but suitable for general-utility and construction purposes)
    - Lumber suitable for use without waste
      - No. 1 boards (sound and tight-knotted stock; size of defects and blemishes limited; may be considered water-tight lumber)
      - No. 2 boards (allows large and coarse defects; may be considered graintight lumber)
    - Lumber permitting waste
      - No. 3 boards (allows larger and coarser defects than No. 2 and occasional knot holes)
      - No. 4 boards (low-quality lumber admitting the coarsest defects, such as decay and holes)
      - No. 5 boards (must hold together under ordinary handling)

TABLE 15.—*Summary of American standard thicknesses and widths* [1] *for softwood yard lumber, including finish, boards, dimension, and heavy joist, siding, flooring, ceiling, partition, shiplap, and dressed and matched lumber*

Product	Rough green or nominal sizes (board measure)		Minimum rough-dry dimensions			Dressed dimensions		
	Thickness	Width	Thickness		Width	Thickness		Width (face when worked)
			Standard yard [2]	Standard industrial		Standard yard	Standard industrial	
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Finish	-------	3	--------	----------	2¾	5/16	----------	2⅝
	-------	4	--------	----------	3⅝	7/16	----------	[3] 5½
	-------	5	--------	----------	4⅝	9/16	----------	[3] 4½
	-------	6	--------	----------	5⅝	11/16	----------	[3] 5½
	1	7	29/32	[4] 39/32	6⅝	25/32	26/32	6½
	1¼	8	1 3/16	----------	7⅜	1 1/16	----------	[3] 7¼
	1½	9	1 7/16	----------	8⅜	1 5/16	----------	[3] 8¼
	1¾	10	1 9/16	----------	9⅜	1 7/16	----------	[3] 9¼
	2	11	1⅝	[2] 1⅞	10⅜	1⅝	1⅝	[3] 10¼
	2½	12	2¼	----------	11⅜	2⅛	----------	[3] 11¼
	3	--------	2⅝	----------	--------	2⅝	----------	----------

[1] The thicknesses apply to all widths and the widths to all thicknesses, with the following exceptions: In tongue-and-groove flooring and in tongue-and-groove and shiplapped ceiling 5/16, 7/16, and 9/16-inch thick, board measure, the tongue or lap shall be 3/16 inch wide, with over-all widths 3/16-inch wider than the face widths shown above. In all other patterned material, 1 1/16, ¾, 1, 1¼, and 1½ inches thick, board measure the tongue shall be ¼ inch wide in tongue-and-groove lumber and the lap ⅜ inch wide in shiplapped lumber with the over-all widths ¼ and ⅜ inch wider, respectively, than the face widths shown above. In patterned material 2 inches and thicker, board measure, the tongue shall be ⅜ inch wide in tongued and grooved (D & M) lumber and the lap ½ inch wide in shiplapped lumber, with the over-all width ⅜ inch and ½ inch wider, respectively, than the face widths shown above.

[2] 20 percent may be 1/32-inch scant.

[3] Based on kiln-dried lumber.

[4] 10 percent may be 1/32-inch scant.

[17] The commercial grade names used by the lumber industry in grade marking and in sales are followed here in order to be of maximum assistance to the reader.

TABLE 15.—*Summary of American standard thicknesses and widths for softwood yard lumber, including finish, boards, dimension, and heavy joist, siding, flooring, ceiling, partition, shiplap, and dressed and matched lumber*—Con.

Product	Rough green or nominal sizes (board measure)		Minimum rough-dry dimensions			Dressed dimensions		
			Thickness			Thickness		
	Thickness	Width	Standard yard [2]	Standard industrial	Width	Standard yard	Standard industrial	Width (face when worked)
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Common boards and strips	1	3	29/32	[4] 30/32	2 3/4	25/32	25/32	2 5/8
	1 1/4	4	1 3/16	----	3 3/4	1 1/16	----	3 5/8
	1 1/2	5	1 7/16	----	4 3/4	1 5/16	----	4 5/8
	----	6	----	----	5 3/4	----	----	5 5/8
	----	7	----	----	6 3/4	----	----	6 5/8
	----	8	----	----	7 5/8	----	----	7 1/2
	----	9	----	----	8 5/8	----	----	8 1/2
	----	10	----	----	9 5/8	----	----	9 1/2
	----	11	----	----	10 5/8	----	----	10 1/2
	----	12	----	----	11 5/8	----	----	11 1/2
Bevel siding	----	4	----	----	----	[5] 7/16 by 3/16	----	3 1/2
	----	5	----	----	----	[5] 9/16 by 3/16	----	4 1/2
	----	6	----	----	----	----	----	5 1/2
Wide bevel siding	----	8	----	----	----	[5] 7/16 by 3/16	----	7 1/4
	----	10	----	----	----	9/16 by 3/16	----	9 1/4
	----	12	----	----	----	[5] 11/16 by 3/16	----	11 1/4
Rustic and drop siding (shiplapped)	----	4	----	----	----	9/16	----	3 1/8
	----	5	----	----	----	3/4	----	4 1/8
	----	6	----	----	----	----	----	5 1/16
	----	8	----	----	----	----	----	6 7/8
Rustic and drop siding (D. & M.)	----	4	----	----	----	9/16	----	3 1/4
	----	5	----	----	----	3/4	----	4 1/4
	----	6	----	----	----	----	----	5 3/16
	----	8	----	----	----	----	----	7
Flooring	----	2	----	----	----	5/16	----	1 1/2
	----	3	----	----	----	7/16	----	2 3/8
	----	4	----	----	----	9/16	----	3 1/4
	1	5	----	----	----	25/32	----	4 1/4
	1 1/4	6	----	----	----	1 1/16	----	5 3/16
	1 1/2	----	----	----	----	1 5/16	----	----
Ceiling	----	3	----	----	----	5/16	----	2 3/8
	----	4	----	----	----	7/16	----	3 1/4
	----	5	----	----	----	9/16	----	4 1/4
	----	6	----	----	----	1 1/16	----	5 3/16
Partition	----	3	----	----	----	3/4	----	2 3/8
	----	4	----	----	----	----	----	3 1/4
	----	5	----	----	----	----	----	4 1/4
	----	6	----	----	----	----	----	5 3/16
Shiplap	1	4	----	----	----	25/32	----	3 1/8
	----	6	----	----	----	----	----	5 1/8
	----	8	----	----	----	----	----	7 1/8
	----	10	----	----	----	----	----	9 1/8
	----	12	----	----	----	----	----	11 1/8
Dressed and matched	1	4	----	----	----	25/32	----	3 1/4
	1 1/4	6	----	----	----	1 1/16	----	5 1/4
	1 1/2	8	----	----	----	1 5/16	----	7 1/4
	----	10	----	----	----	----	----	9 1/4
	----	12	----	----	----	----	----	11 1/4
Dimension and heavy joist	2	2	1 3/4	[2] 1 7/8	1 3/4	1 5/8	1 3/4	1 5/8
	2 1/2	4	2 1/4	----	3 3/4	2 1/8	----	3 5/8
	3	6	2 3/4	----	5 3/4	2 5/8	----	5 5/8
	4	8	3 3/4	----	7 5/8	3 5/8	----	7 1/2
	----	10	----	----	9 5/8	----	----	9 1/2
	----	12	----	----	11 5/8	----	----	11 1/2
Factory flooring, heavy roofing, heavy decking, and sheet piling	2	4	1 3/4	----	----	1 5/8	----	[6] 3
	2 1/2	6	2 1/4	----	----	2 1/8	----	[6] 5
	3	8	2 3/4	----	----	2 5/8	----	[6] 7
	4	10	3 3/4	----	----	3 5/8	----	[6] 9
	----	12	----	----	----	----	----	[6] 11

[2] 20 percent may be 1/32-inch scant.
[4] 10 percent may be 1/32-inch scant.
[5] Minimum.
[6] Face width when shiplapped; when dressed and matched the face width is 1/8-inch greater; when grooved for splines the face width is 1/2-inch greater.

Finish or Select Lumber—Grade Qualities

Select grades [18] provide for good appearance and finishing qualities, grades A and B are suitable for natural, and grades C and D for paint finishes. In a few species where there is a pronounced difference in color between heartwood and sapwood and where high natural resistance to decay is required, a grade of clear heart is available.

Grade A is practically clear wood. It is manufactured for such items as finish, flooring, ceiling, partition, and siding. A large number of manufacturers do not segregate the grade even in these items, and some of the lumber associations do not recognize the quality as a separate grade. Where the grade is not segregated it is combined with B grade and sold as B and Better. Grade A lumber is used almost entirely for interior and exterior trim and for flooring. The demand is small and confined largely to high-class construction, such as office buildings and the higher cost residences.

Grade B allows a few small imperfections. In practice these small imperfections mainly take the form of minor skips in manufacture and small checks or stain due to seasoning, and, depending on the species, small pitch areas, pin knots, or the like. Grade A pieces in the mixed grade are practically clear, but the average board contains 1 to 2 small imperfections. Grade B and Better is the highest quality segregated in a number of woods. In construction it is the grade most commonly used for high-class interior and exterior trim, especially where these are to receive a natural finish. It is the principal grade used for flooring in homes, offices, and public buildings. In industrial uses it meets the special requirements for large-sized practically clear stock.

Grade C is classified as allowing a limited number of small imperfections that can be easily covered with paint. Specifically, the number of these per board averages about twice that of B and Better, and the proportion of them in grade C that are small knots is greater than in B and Better. Grade C lumber is especially adapted to use where a high-class paint finish is desired. It is, therefore, popular for cornice, and other exteriors of dwellings, porch flooring, porch columns, trim for bedrooms and kitchens, built-in kitchen fixtures, and siding for the better class of structures. It is used to some extent for natural finishes in medium- and low-priced dwellings and offices.

Grade D is classified as allowing any number of surface imperfections that do not detract from the appearance of the finish when painted. In practice the number of such surface features per board averages 3 to 5 times as many as in B and Better. Certain natural and manufacturing imperfections are not much more numerous in grade D than in grade C, but the number and size of the knots in grade D are considerably greater than in grade C, and usually the back is of somewhat lower quality. Commercial grading permits an occasional coarse knot or hole in grade D that may be cut out with restrictions as to waste. Grade D is in reality a one-face

[18] Detailed descriptions, photographs, and use recommendations for the various grades are given in pamphlets entitled "Lumber Grade-Use Guide", issued by the National Lumber Manufacturers' Association, Washington, D. C.

grade—that is, only one face shows in actual use. Grade D is used in construction for the same uses as grade C. It goes into moderate- or low-priced houses, furnishing a medium-priced lumber for casing, cornice work, shelving, and built-in fixtures that are to be painted. It is also used extensively for millwork and molding, and is adaptable to industrial uses requiring short-length clear lumber.

The knots occurring in grade B and Better are predominantly under one-half inch in diameter and have smooth, hard surfaces. A small proportion of the knots in grade C are as large as 1 inch in diameter, and a few are not of the best quality. A few knots in grade D lumber are more than 1 inch in diameter and in quality are slightly soft, rough, or loose.

Depending on the species, the highest commercially recognized grade may be C and Better, or D and Better, but no such combination of grades, except B and Better, is recognized in American lumber standards unless the actual proportions in the mixed grade are specified in the invoice.

Seasoning faults, such as check, either in flat surfaces or at the ends of boards, are among the more frequent imperfections in the select grades. Imperfect seasoning often causes a lowering of grade, but the number of such occurrences is considerably reduced at plants of careful manufacturers.

Pitch pocket is a relatively common feature in the select grades of several species but occurs less frequently than knots in all the important species except one. The variation among grades in the number and size of pitch pockets is not so marked as in the case of knots. The frequency of pitch pockets as compared with other forms of pitch varies considerably among the species.

Among the other features that are factors in the select grades are stain and chipped and torn grain.

Boards—Grade Qualities

Grades of boards [19] contain features that detract from the appearance of the finish but are suitable for general utility and construction purposes. The differences between the various board grades are due to the character more than to the number of such features as knots, pitch, and the like. The number of knots and the like in a board averages in different species about 5 to 20 per 8 board feet regardless of grade. No. 1 and no. 2 boards are for use without waste. No. 3, no. 4, and no. 5 boards permit a limited amount of waste.

No. 1 boards are described in the basic classification as sound and tight-knotted stock in which the size of the knot is limited. The provisions further state that it may be considered watertight lumber. In most species practically all boards in the grade contain knots, although in some species pitch is the predominant characteristic of the grade. The size of the knots varies with the species. From one-half to three-fourths of the knots are usually intergrown; the remaining knots are incased, a small proportion of which are unsound, broken, or checked.

No. 1 boards are used in construction both for finish and covering. As a finishing lumber this grade is used for siding, cornices, and

[19] See footnote 18, p. 83.

other exterior trim in medium- and low-priced homes, and for sheathing and roof boards in the more expensive type of buildings. It is well adapted to coverage for farm buildings, especially where a weathertight structure is required. Its use for interior trim is confined to cheaper construction and where high-class paint finishes are not required. In this grade it is difficult to conceal entirely the knots with paint. The no. 1 board is a general-utility item in industrial use. It is used extensively for door and window frames and for backing and concealed parts of furniture and fixtures.

No. 2 boards are classified as allowing large and coarse features such as knots that may be considered grain-tight. In practice a small amount of through-shake, through-pitch pockets, and decay is permitted in the grade. The proportion of large knots is greater than in no. 1, and whereas 33 to 75 percent of the knots are intergrown, 10 percent or more are usually unsound, loose, or otherwise partially open. Some commercial grading rules allow knot holes in the grade, provided they are strictly limited as to size and number. No. 2 boards are used primarily as coverage where the wood is not painted or otherwise finished. Subfloors, sheathing, and concrete forms are typical uses for the grade. Dressed and matched, it is used for rough flooring in inexpensive farm and factory buildings, garages, warehouses, and the cheaper types of cottages. It is extensively used for barn boards laid up vertically and for the form of drop siding for barns, garages, and warehouses. The popular type of knotty finish is largely selected from this grade. Industrially no. 2 boards go into the same uses as no. 1 boards, but are better adapted to uses requiring short length or small pieces than to uses requiring the board as a whole.

No. 3 boards are classified as allowing larger and coarser knots than no. 2 boards and also occasional knot holes. A larger portion of large knots and increased amounts of shake, decay, and holes distinguish no. 3 boards from no. 2 boards. No. 3 boards are used in construction for concrete forms, sheathing, subfloors, roof boards, barn boards, and temporary construction. They fill a demand from builders of less exacting type of buildings for a cheaper material than no. 2. Industrially it is extensively used for boxes and crates, and in some species for founding flasks.

Grades no. 4 and no. 5 boards are provided for in American lumber standards but are not produced in some species. No. 4 is described in the basic-grade classification as a low-quality lumber admitting of the coarsest features, such as decay and holes. The only requirement as to the quality of no. 5 lumber is that it hold together under ordinary handling.

No. 4 boards are not graded for use as a whole. They are used for sheathing, subfloors, and roof boards in the cheaper types of construction. The use of the grade for these purposes involves some additional labor and a small amount of waste in cutting out defective material. Boxes and crates are the most important industrial outlet for the grade.

No. 5 boards are seldom shipped far from the mill and are, therefore, not commonly available at retail yards in nonforested regions. They are used for rough and temporary coverage of buildings and for boxes and crates.

In cases where commercial grading rules divide the entire range of boards into 3 grades instead of 5 grades as in American lumber standards, the first or highest grade of the 3-grade division will normally contain material with a wider range in quality than the first grade of the 5-grade division, and the third or lowest grade of the 3-grade division will contain lower-quality material than the third grade of the 5-grade division. This fact and the differences in inherent properties of different species make it impossible to consider the common grades of corresponding name for the different woods as interchangeable in use.

In most species one-third to two-thirds of the knots in the grades of boards are intergrown, whereas in the select grades of finish items intergrown knots comprise only a small proportion of the total. Intergrown knots may check if large, but they do not loosen or drop out, as they are integral parts of the wood.

In some species a large number of the incased knots remain tight, but in other species many of them loosen. The loosening becomes more pronounced in large knots and as the lumber becomes drier. As a rule incased knots comprise a larger percentage of the total number of knots in the small-knotted select grades than they do in the larger-knotted grades of boards.

Spike knots are formed by cutting a branch lengthwise rather than crosswise as is the case with round knots. Spike knots occur infrequently in grades better than no. 2 boards.

Wood that contains small areas of clearly evident decay is not permitted in grades better than no. 2 boards.

Dimension

Dimension is lumber 2 to 5 inches in thickness and of any width. It is manufactured only in nos. 1, 2, and 3 dimension grades.

Dimension is graded primarily on its strength, stiffness, and straightness. Grading is based principally on the requirements of framing for buildings. The dimension grades are best adapted to use where stiffness is the controlling factor as in joists and studs or where the size of the member is determined by common building practice rather than specially designed to carry definite live and dead loads.[20] Rafters of dwelling houses are good examples of members whose size is generally determined by common practice rather than by special design.

No. 1 dimension is a sound grade allowing knots limited in size depending on the size of the piece. Features, such as pitch, torn grain, checks, and stain, that do not materially affect the strength of the piece are not limited. Wane is limited to provide good nailing on one side and two edges.

The grade is for joists, rafters, scaffolding, in light framing and for less exacting items in heavier framing. Likewise it is used for planking for warehouses, platforms, and other heavy-duty flooring, where the wearing surface rather than load-carrying ca-

[20] Where members are designed to carry heavy loads and where strength rather than stiffness is the controlling factor, as in heavy construction, the structural grades of joists and plank (p. 108) should be used in preference to the dimension grades, as the structural grades are more scientifically graded and definite working stresses can be assigned to them.

pacity is the important factor. The structural grades of joists and plank should be used in preference to dimension grades for flooring designed to carry heavy loads.

No. 2 dimension admits large, coarse, unsound knots, warped pieces, certain types of decay, has fair nailing edges, and other features that will not weaken the piece to an extent that will render it unfit for use as a whole.

It is used in construction for joists and rafters in medium-priced light-frame construction and for plates, sills, studding, and other vertical load-bearing members in high-priced light construction. It is used as flooring to provide wearing surface where the load is not carried by the wood floor. Industrially it is used for crating and other uses where short lengths are required.

No. 3 dimension is described generally as including all pieces falling below the grade of no. 2 that are suitable for use in cheap building. It admits all features of no. 2 without limitations on size or number providing they do not seriously affect the utility of the piece or involve waste of more than 25 percent in one third of the pieces. It is used for studding in low-priced and temporary light-frame construction. In small buildings where the members are short, no. 3 dimension may be cut and used with considerable economy.

STRUCTURAL MATERIAL—SIZE STANDARDS

Structural material is divided into three classes—joist and plank, beams and stringers, and posts and timbers (p. 108). Standard lengths in all three classes are in multiples of 2 feet, except for the following odd lengths which are allowed:

	Feet
2 by 4, 6 by 8 inches	9 and 11
2 by 8 inches	13
2 by 10 inches	13 and 15
8 by 8, 10 by 10, 12 by 12, 14 by 14, 16 by 16, 18 by 18 inches	11 and 13
6 by 16, 6 by 18, 8 by 16, 8 by 18 inches	15 and 17

The thicknesses and widths adopted as standard for each of the three classes of structural material are given in table 16.

TABLE 16.—*American standard thicknesses and widths for structural material*

[The thicknesses apply to all widths and the widths to all thicknesses]

Structural item	Thicknesses			Widths		
	Nominal thickness	Permissible minimum rough thickness [1]	Dressed thickness (S1S or S2S)	Nominal width	Permissible minimum rough width [1]	Dressed width (S1E or S2E)
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Joist and plank	2	1/8 off	3/8 off	4 to 7	3/16 off	3/8 off.
	3 and 4	3/16 off		8 and wider	1/4 off	1/2 off.
Beams and stringers	5 and 6	do	1/2 off	do	do	Do.
	7 and thicker	1/4 off				
Posts and timbers	5 by 5, 6 by 6, 8 by 8, and larger.	3/16 off	do	5 by 5, 6 by 6, 8 by 8, and larger.	3/16 off	Do.
		1/4 off			1/4 off	

[1] No shipment shall contain more than 20 percent of pieces of the permissible minimum rough thicknesses or widths specified here.

STRUCTURAL MATERIAL—GRADE STANDARDS

Structural material is graded on a basis of strength and is intended for use where working stresses are required. A full discussion of structural grades and appropriate working stresses appears on pages 99 to 118.

FACTORY AND SHOP LUMBER—SIZE STANDARDS

Standard lengths of factory and shop lumber are 6 feet and over in multiples of 1 foot, except the box grade of shop lumber, in which the standard lengths are 4 feet and over.

Standard widths are 5 inches and over, and are usually shipped in random widths.

Standard thicknesses are given in table 17.

TABLE 17.—*Standard thicknesses of factory and shop lumber*

Nominal thickness (inches)	Finished thicknesses S1S or S2S	Nominal thickness (inches)	Finished thicknesses S1S or S2S
	Inches		*Inches*
1	25/32 or 26/32	2¼	2⅛
1¼	1 5/32	2½	2⅜
1½	1 13/32	3	2⅝
2	1 26/32	4	3⅝

FACTORY AND SHOP LUMBER—GRADE STANDARDS

Factory and shop lumber is divided into two classes from the standpoint of use—factory plank and shop lumber—each of which has a different set of grades. These grades are based on the percentage of the area of each board or plank that will furnish cuttings of specified sizes and qualities except in the upper grades of shop lumber of all thicknesses.

Factory plank is 1¼ inches or more in thickness and is used largely for door and sash cuttings. The No. 1 cuttings referred to in the following grade requirements for factory plank must be free of defects on both sides. The no. 2 cuttings may contain any one of the following seven defects: a limited amount of blue or brown stain, a small tight knot, a small pitch pocket or streak, small season checks, and slightly torn grain. The cuttings are of various lengths and widths, depending on the door (or sash) parts for which they are used.

The basic grade classifications for softwood factory plank (American lumber standards) are as follows:

- Factory plank (factory lumber graded with reference to its use for doors, sash, and other cuttings)
  - Factory clears (upper grades of factory plank containing a high percentage of best-quality cuttings)
    - Nos. 1 and 2 clear factory (lumber practically clear in wide sizes, to contain not less than 85 percent of no. 1 door cuttings, not including pieces with over two muntins, or muntins only)
    - No. 3 clear factory (lumber containing not less than 70 percent of no. 1 door cuttings, not including pieces with over two muntins, or muntins only)

- Factory plank (factory lumber graded with reference to its use for doors, sash, and other cuttings)—Cont'd.
  - Shop (lower grades of factory plank yielding smaller percentages in smaller and lower quality cuttings)
    - No. 1 shop (lumber of high-quality factory grade containing not less than 50 percent of no. 1 door cuttings, allowing, if necessary, one no. 2 stile in any piece, but no pieces with over two muntins, or muntins only)
    - No. 2 shop (lumber containing not less than 25 percent of no. 1 door cuttings, or 40 percent of no. 2 door cuttings, or 33⅓ percent of mixed door cuttings)
    - No. 3 shop (lumber of a shop type below the grade of no. 2 shop and better than box lumber)

Shop lumber is used for general cut-up purposes. The (*a*) cuttings referred to in the following grade requirements for shop lumber must be at least 9½ inches wide and 18 inches long, and the (*b*) cuttings at least 5 inches wide and 3 feet long. (*a*) Cuttings less than 3 feet long must be free from defects on both sides. Other (*a*) cuttings together with (*b*) cuttings will allow a limited number of small defects that can be covered with paint. Shop lumber grades in some woods are available in only 1-inch stock. Thick stock in these woods for cut-up purposes is bought under factory-plank rules.

The basic grade classifications for softwood shop lumber (American lumber standards) are as follows:

- Shop lumber (shop lumber graded for cuttings of minimum and larger sizes, or for permissible defects, with reference to its use for general cut-up purposes)
  - 1-inch thick (applies to northern and western pines and other West-coast woods)
    - Select (lumber to contain not less than 70 percent of (*a*) and/or (*b*) cuttings)
    - Shop (lumber to contain not less than 50 percent of (*a*) and/or (*b*) cuttings)
  - All thicknesses (applies to cypress, redwood, and western red cedar)
    - Tank and boat stock (lumber admitting sound defects that do not impair the usefulness of each piece for the use intended)
    - Firsts and seconds (lumber of C select or better quality on the reverse side, suitable for remanufacture into products requiring both faces of good quality
    - Selects (lumber of C select or better quality on the face side, suitable for remanufacture into products requiring one face of good quality
    - No. 1 shop (lumber to contain not less than 60 percent of (*a*) and/or (*b*) cuttings)
    - No. 2 shop (lumber to contain not less than 40 percent of (*a*) and/or (*b*) cuttings
    - Box (lumber below the grade of no. 2 shop to contain not less than 66⅔ percent sound cuttings not less than 3 inches wide and 18 inches long)

STANDARD LUMBER PATTERNS

Figure 9 shows six typical patterns of lumber.

With softwood flooring, "standard match" means that the upper lip of the groove is thicker than the lower. The thickness of the lower lip is the same for all standard thicknesses of flooring, and hence the difference between upper and lower lips becomes more pronounced in the heavier thicknesses. Ceiling, which is thinner than 1 inch, is usually machined with a bead and a V. Partition usually has the bead and V, also, but on both sides, and it is thicker than ceiling. Drop siding is usually made from 1-inch lumber and probably is made in more patterns than any other product except molding. Some of these patterns are shiplapped, while others are tongued and grooved. Bevel siding is made by resawing 4/4-inch or 5/4-inch lumber on an angle. Square-edged lumber in either boards, timbers, or dimension, of course, forms only rectangles of different dimensions. Boards are frequently dressed and matched (D&M), in which event the tongue and groove are in the center, making the pieces center matched. For some uses it is considered preferable to shiplap boards.

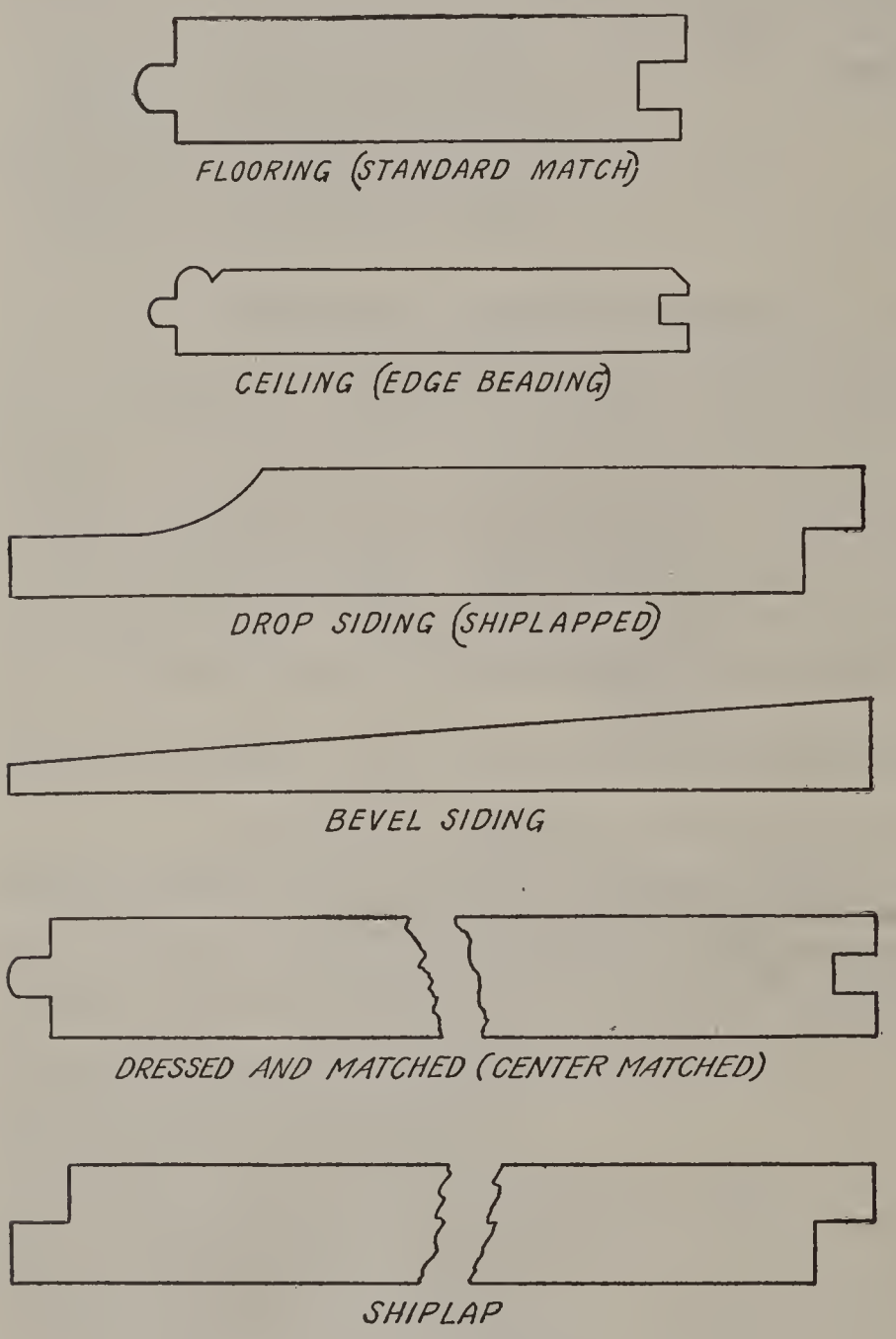


FIGURE 9.—Six typical patterns of lumber.

LUMBER ITEMS USUALLY CARRIED IN RETAIL YARDS

The small retail yards throughout the United States carry softwoods required for ordinary construction purposes and sometimes small stocks of 1 or 2 hardwoods in the grades suitable for finishing or cabinetwork. Any particular hardwood desired, however, may be obtained by special order through the retail lumber yard. Hardwoods are used in building chiefly for interior trim, cabinets, and flooring. In modern practice, trim items are cut to size in standard pattern at millwork plants and are sold in such form by the retail yards. Cabinets are usually made by the millwork plant ready for

installation on the job by the carpenter. Hardwood flooring invariably is a planing-mill product and is available to the buyer only in standard patterns.

The assortment of species in general construction items carried by retail yards depends largely upon geographical location. For instance, in the Pacific Northwest local yards will, as a rule, stock Douglas fir, spruce, ponderosa pine, western hemlock, and western red cedar. An Iowa yard will stock eastern hemlock, northern white pine, ponderosa pine, southern yellow pine, and Douglas fir. For some species only certain items of various species may be available; for example, southern yellow pine or Douglas fir may be stocked only in the form of dimension or piece items, eastern hemlock only in sheathing and inch boards, cypress and redwood in finish boards and plank or in siding. A New York market might stock eastern spruce and hemlock, northern white pine, cypress, ponderosa pine, southern yellow pine, and Douglas fir. In the eastern part of the United States lumber from the Pacific coast is readily available because of low-cost water transportation via the Panama Canal.

Wholesalers do not ordinarily stock lumber. However, some large wholesalers located in extensive lumber-consuming districts have yards wherein are stocked many kinds of lumber, both of hardwood and softwood. These wholesalers supply the varied needs of retail yards, wood-using factories, and larger contractors, although purchases are sometimes made directly from the lumber mills.

Lumber is sold in a number of standard general-purpose items and also in certain special-purpose items. Retail yards carry all the general-purpose items, but as a rule only the more important of the special-purpose items. Some of these lumber items come in one group of grades and some in another. There are not many items made in the complete range of grades. Among the typical special-purpose items are stepping, casing and base, silo staves, molding, battens, window and door jambs, and porch columns. The lumber items commonly carried by all retail yards are described as follows:

COMMON BOARDS

Common boards, so-called, or boards are a general-purpose item available at all yards in one or more of the kinds of wood most frequently used in building. Boards are usually of nominal 1-inch thickness dressed two sides to twenty-five thirty-seconds inch thick. Sometimes thinner stock is offered, but it should not be classed as standard lumber. The standard nominal widths are 6, 8, or 10 inches or sometimes wider. Boards are manufactured in all grades from no. 1 to no. 5, but only no. 1, no. 2, and no. 3 are generally available in retail yards.

Boards are sold square edge, dressed and matched (tongue-and-groove) or with a shiplap joint. The largest uses for common boards are subfloors, sheathing, barn boards, roofing boards, rough siding, and concrete forms.

DIMENSION

Dimension is primarily framing lumber, such as joists, rafters, and studding. It also comprises the planking used for heavy floors. Strength, stiffness, and uniformity of size are essential requirements.

It is stocked in all yards frequently in only one of the general-purpose construction woods, such as pine, fir, hemlock, or spruce. It is usually nominal 2 inches in thickness dressed 1 or 2 sides to 1⅝ inches, nominal 4, 6, 8, 10, or 12 inches in width and 4 to 18 feet long in multiples of 2 feet. Dimension thicker than 2 inches and longer than 18 feet is manufactured but only in comparatively small quantities. The grades are no. 1 dimension, no. 2 dimension, and no. 3 dimension.

FINISH

Finish, except for such special types as knotty pine and pecky cypress, is of select quality and is made in practically all softwoods, although a local lumber yard usually stocks only a few kinds. It is manufactured in all select grades but principally B and Better and C. It is usually nominal 1 inch, dressed 2 sides to twenty-five thirty-seconds inch, although nominal 1¼ inches and 1½ inches are frequently stocked. The widths usually stocked are 5 to 12 inches in both odd and even inches. Finish goes principally into interior and exterior trim although it has numerous other uses.

SIDING

Siding, as the name implies, is made specifically for purposes of exterior coverage. It is of two principal types, bevel siding and drop siding; the latter also known as rustic siding or barn siding. Bevel siding is ordinarily stocked only in the select grades of white pine, ponderosa pine, western red cedar, cypress, or redwood. Drop siding is sometimes stocked both in select and in sound, tight-knotted utility grades of southern pine, Douglas fir, and hemlock, in addition to the woods mentioned under bevel siding. Bevel siding may be of the narrow type 3½-, 4½-, or 5½-inch face width, or of the wide type 7¼-, 9¼-, or 11¼-inch face width. The narrow type is seven-sixteenths or ten-sixteenths inch thick, the wide type seven-sixteenths, nine-sixteenths, or eleven-sixteenths inch thick. Drop siding is ordinarily 5-, 6-, or 8-inch nominal width and dressed to thickness of three-fourths inch. It may be either dressed or matched or shiplapped.

CEILING AND PARTITION

Ceiling and partition are not made or stocked as commonly as in former years although they are still popular items, usually in the select grades. Although, as their name indicates, they are manufactured for a specific use, they are often used for a variety of purposes requiring a finished appearance and where a simple pattern is preferred to plain unbroken surfaces. Ceiling and partition may be 2⅜-, 3¼-, 4¼-, and $5\frac{3}{16}$-inches face width. Ceiling is five-sixteenths, seven-sixteenths, nine-sixteenths, and eleven-sixteenths inch thick, and partition is three-fourths inch thick. Ceiling in thin patterns may be lapped. All thicknesses are dressed and matched.

FLOORING

Flooring is made chiefly in the harder softwood species, such as Douglas fir, western larch, and southern pine, and in hardwoods, such as maple and oak. At least 1 of the softwoods and usually

2 hardwoods are stocked in most yards. Flooring is usually nominal 1 inch dressed to twenty-five thirty-seconds inch and 3- and 4-inch nominal width. Thicker flooring is available for heavy-duty floors both in hardwoods and softwoods. Thinner flooring is available in hardwoods, especially for recovering old floors. Vertical and flat grain (also called quarter-sawed and plain-sawed, respectively,) are manufactured in both softwoods and hardwoods, and many dealers carry both types in stock.

Vertical-grain flooring shrinks and swells less than flat-grain flooring, is more uniform in texture, wears more uniformly, and the joints do not open so much.

Softwood flooring is usually available in B and Better grade, C Select, or D Select. The chief grades in maple are Clear No. 1 and No. 2. The grades in quarter-sawed oak are Clear, Sap Clear, and Select, and in plain-sawed Clear, Select, and No. 1 Common. The quarter-sawed has the same advantages that vertical-grain softwood flooring has. In addition the silver or flaked grain of quarter-sawed material is frequently preferred to the figure of plain-sawed material. Beech, birch, and for fancy parquetry flooring walnut and mahogany are also used.

CASING AND BASE

Casing and base is a standard item in the more important softwoods and is stocked in most yards in at least one species. The chief grade is B and Better. It is made and graded to meet the requirements of interior trim for dwellings. It is usually nominal 1-inch stock dressed to three-fourths inch of 5-, 6-, and 7-inch nominal widths. Hardwoods for the same purpose, such as oak and birch, may be carried in stock in the retail yard or may be obtained and manufactured on special order at the local planing mill.

MOLDINGS

Standard moldings of the so-called "7,000" series, set up under American lumber standards, are of good design and are approved by architectural and manufacturing organizations. Such moldings are now available to builders as stock items through retail yards and cover a wide variety of patterns and sizes.

SHINGLES

Shingles are made from western red cedar, southern cypress, northern white cedar, and redwood. Western red cedar furnishes the greater proportion. The shingle grades of western red cedar are No. 1, No. 2, and No. 3; cypress, No. 1—bests, primes, economies, and clippers; northern white cedar—extra star A star, standard star A star, and sound butts; and redwood, No. 1 and No. 2. The western red cedar No. 1 grade, tidewater red cypress No. 1, and redwood No. 1 meet the requirements of No. 1 grade of commercial standards as promulgated by the Department of Commerce. These highest grades, which are usually the most economical grades for permanent construction, are all clear, all heartwood, and all edge grain. Shingles that are all heartwood give greater resistance to decay than do shingles that contain sapwood. Edge-grain shingles are less

likely to warp than flat-grain shingles; thick-butted shingles less than thin shingles; and narrow shingles less than wide shingles. The standard thicknesses of shingles are described as 4/2, 5/2¼, and 5/2 meaning, respectively, 4 shingles to 2 inches of butt thickness, 5 shingles to 2¼ inches of butt thickness, and 5 shingles to 2 inches of butt thickness. Lengths may be 16, 18, or 24 inches. Random widths and specified widths ("dimension" shingles) are available in western red cedar, redwood, and southern cypress; random widths, in northern white cedar. Random-width shingles are usually packed by the square, dimension by the thousand shingles.

LATH

Lath are made in nearly all the important softwoods. The chief grades are No. 1 and No. 2.

GRADE-MARKED LUMBER AND MOISTURE-CONTENT PROVISIONS

Grade-marked and trade-marked lumber for some time past has been available in some species and items and now is extended further under the provisions of the N. R. A. lumber code. Each piece of such lumber typically is stamped with its proper grade, with a number identifying the mill where it was made, and with the mark of the lumber association promulgating the grading rules. Provisions of the lumber code require marking also for species, size, and whether seasoned or unseasoned, according to the definitions of the term set up by each divisional code agency. The grade designation stamped on a board indicates the quality at the time the piece was graded. Subsequent exposure to unfavorable storage conditions, improper drying, or careless handling may cause the material to fall below its original grade.

Lumber may be purchased under moisture-content provisions. The allowable moisture content is lower in the thinner material and in the select grades. In one specification for kiln-dried 4/4-inch and 5/4-inch lumber of C and Better quality, for instance, the moisture content must not exceed 12 percent in 90 percent of the pieces, and the remainder must not exceed 15-percent moisture content. For thicker select lumber and for kiln-dried boards and dimension the allowable moisture-content values run up to 15 percent for 90 percent of the pieces and 18 percent for the remainder. Specifications for air-dried lumber are expressed similarly but the allowable moisture-content values are higher, ranging from 16 percent and 19 percent for 4/4-inch C and Better up to 19 percent and 22 percent for 8/4-inch dimension.

POINTS TO CONSIDER WHEN ORDERING SOFTWOOD LUMBER OR TIMBER

The following excerpt from a Federal specification lists some of the points to be considered when ordering softwood lumber or timber:

1. Quantity: Feet, board measure, number of pieces if of definite size and length, etc.

2. Size: Thickness in inches—nominal and also actual if surfaced on faces. Width in inches—nominal and also actual if surfaced on edges. Length in feet—may be nominal average length, limiting lengths or a single uniform length.

3. Grade: No. 1 Dimension, B and Better, etc., as indicated in grading rules of lumber manufacturers' associations.
4. Species of wood: Douglas fir, southern cypress, etc.
5. Product: Flooring, siding, timbers, boards, etc.
6. Condition of seasoning: Air-dry, kiln-dry, commercially shipping dry, etc. (Definite interpretation of requirements in this respect necessitate specifying in terms of moisture-content and how it is to be determined.)
7. Surfacing: Indicate whether rough (unplaned) or dressed (surfaced) stock is desired. S1S means surfaced on one side. S2S means surfaced on two sides. S1S1E means surfaced on 1 side and 1 edge. S4S means surfaced on four sides.
8. Association rules: Southern Pine Association, Western Pine Association, etc.

STANDARD LUMBER ABBREVIATIONS

The following standard lumber abbreviations are in common use in contracts and other documents arising in the transactions of purchase and sale of lumber:

AD—air dried.
a. l.—all lengths.
av.—average.
av. w.—average width.
av. l.—average length.
a. w.—all widths.
B1S—beaded one side.
B2S—beaded two sides.
BBS—box bark strips.
bd.—board.
bd. ft.—board foot; that is, an area of 1 square foot by 1 inch thick.
bdl.—bundle.
bdl. bk. s.—bundled bark strips.
Bev.—beveled.
b. m.—board (foot) measure.
Btr.—better.
Clg.—ceiling.
Clr.—clear.
CM.—Center matched; that is, the tongue-and-groove joints are worked along the center of the edges of the piece.
Com.—common.
Csg.—casing.
Ctg.—crating.
cu. ft.—cubic foot.
D&CM—dressed (1 or 2 sides) and center matched.
D&H—dressed and headed; that is, dressed 1 or 2 sides and worked to tongue-and-groove joints on both the edge and the ends.
D&M—dressed and matched; that is, dressed 1 or 2 sides and tongued and grooved on the edges. The match may be center or standard.
D&SM—dressed (1 or 2 sides) and standard matched.
D2S&CM—dressed two sides and center matched.
D2S&M—dressed two sides and (center or standard) matched.
D2S&SM—dressed two sides and standard matched.
Dim.—dimension.
D. S.—drop siding.
E—edge.
E&CB1S—edge and center bead 1 side; surfaced 1 or 2 sides and with a longitudinal edge and center bead on a surfaced face.
E&CB2S—edge and center bead 2 sides; all 4 sides surfaced and with a longitudinal edge and center bead on the 2 faces.
ECM—ends center matched.
E&CV1S—edge and center V 1 side; surface 1 or 2 sides and with a longitudinal edge and center V-shaped groove on a surfaced face.
E&CV2S—edge and center V 2 sides; all 4 sides surfaced and with a longitudinal edge and center V-shaped groove on each of the 2 faces.
E. G.—edge grain.
EM—end matched—either center or standard.

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SOUTHERN PINE ASSOCIATION.
1932. STANDARD SPECIFICATIONS FOR GRADES OF LONGLEAF AND SHORTLEAF SOUTHERN PINE LUMBER AND TIMBER CONFORMING TO AMERICAN LUMBER STANDARDS. 120 pp., illus. New Orleans, La.
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WEST COAST LUMBERMAN'S ASSOCIATION.
1929. STANDARD GRADING AND DRESSING RULES FOR DOUGLAS FIR, SITKA SPRUCE, WEST COAST HEMLOCK, WESTERN RED CEDAR LUMBER. 120 pp., illus. Seattle, Wash.
WESTERN PINE ASSOCIATION.
1934. STANDARD GRADING RULES FOR PONDEROSA PINE, SUGAR PINE, IDAHO WHITE PINE, LARCH, DOUGLAS FIR, WHITE FIR, SPRUCE, AND CEDAR LUMBER. 110 pp., illus. Portland, Oreg.

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STRUCTURAL TIMBERS

In the following pages information is given regarding the factors that affect the strength and hence the grade of structural timbers, and working stresses for various grades (California Redwood Association, Northern Hemlock and Hardwood Manufacturers' Association, Southern Cypress Manufacturers' Association, Southern Pine Association, West Coast Lumberman's Association, and Western Pine Association).[21] Information for the classification of structural timbers into grades within which reasonable uniformity and fairly definite minimums of strength obtain is also given. This classification is, except for amplification and minor modifications, that of American lumber standards (American Railway Engineering Association, American Society for Testing Materials, Bureau of Standards, and Wilson). A procedure for determining the safe working stresses for a grade from basic stresses for clear wood is also given.

CONSIDERATIONS AFFECTING TIMBER GRADES

QUALITY OF WOOD

The strength of the clear wood of any species varies over a considerable range; wood of the lowest strength is undesirable in a strength grade. On the other hand, recognition of the higher strength of the better wood is desirable. Strength is closely related to the weight or density of the wood. Higher strength may be obtained by excluding pieces that are obviously of exceptionally light weight and by using rate of growth and percentage of summer wood in selecting pieces of superior strength from those species in which these characteristics are acceptable criteria. Selection for rate of growth requires the number of annual rings per inch to be within a specified range. Selection for density imposes in addition to limitations of rate of growth the requirement of a minimum percentage of summer wood. It is applied only to those species in which summer wood is well differentiated and is known to be an efficient criterion of strength.

DECAY

Ordinarily, the extent of decay is difficult to determine, no accurate estimate of its effect can be made, and its possible damaging effect with many species of fungi and the chances of further development in service are great. Consequently decay in any form is usually prohibited in strength grades.

SEASONING

Tests of small specimens demonstrate that the strength of wood fibers is greatly increased by drying. In large timbers the increase is less because of the checking that occurs in seasoning. Checks

[21] For further information the references at the end of this section should be consulted.

Beams and stringers, joist and plank, and posts and timbers (p. 108) may be described under a single grade name, but the requirements need not be such as to afford the same strength ratio in each use class. Also, working stress in the extreme fiber of pieces used in bending is determined by the permitted knots and cross grain, whereas shearing stress depends on shakes and checks. Consequently, strength ratios for shear and for stress in extreme fiber may differ in the same grade and a ratio for each kind of stress is necessary to characterize a grade of beams and stringers or of joist and plank.

Economy may be served by specifying these ratios in such relation to each other that the allowable working stresses for shear and for extreme fiber will be in balance, under the loading for which the members are designed. Also timbers of high strength ratio should not be specified for use where stiffness is the controlling factor as is frequently true of joists above plastered ceilings, because stiffness of timbers varies but little with the grade and one value of modulus of elasticity is used for each species regardless of the strength ratio of the grade.

STRENGTH RATIOS AND WORKING STRESSES FOR PUBLISHED GRADES

In table 18 are listed grades produced by a number of associations of lumber manufacturers whose rules describe structural grades in accordance with the principles of strength grading as presented herein.[22] The working stresses recommended by the respective associations for material that will be continuously dry are listed, and strength ratios as found by comparing the grade descriptions with the system presented on pages 108 to 117 are shown for each grade.

Consideration should be given to reducing some of the values in table 18 if the material is to be used where there is a decay hazard, that is, where it will not be continuously dry or wet. The discussion on page 106 will serve as a guide for the proper changes.

Table 19 lists the strength ratios applicable to the grade examples of American lumber standards. These strength ratios also apply to the grades adopted by the American Society for Testing Materials and the American Railway Engineering Association. Approximately equivalent specifications have been incorporated in the standards of numerous other agencies. Working stresses for such grades maye be found by the method outlined on page 106.

FACTORS AFFECTING THE USE OF WORKING STRESSES

The working stresses given in table 18 are for long-continued load and are considered safe under circumstances such that failure would cause personal injury or large property damage. No actual failure

[22] As this handbook goes to press the lumber industry is proposing an entirely new set-up for structural grades and working stresses. Several of the grades listed in table 18 have strength ratios approximately the same, for the several species, but because of difference in strength of the clear wood the working stresses for the different species vary considerably. The lumber industry believes that this has caused confusion among engineers, architects, and consumers and, therefore, are considering the following alternative: (1) The setting up of a series of standard working stress values; (2) the establishment for each species of grades with strength ratios that will permit the use of some or all of the standard working stress values; (3) the designation of grades by the allowable working stress instead of by such grade names as are shown in table 18.

TABLE 18.—*Strength ratios for various lumber-association grades, with working stresses recommended by the producers for material used where it will be continously dry* [1]

Name of association and effective date of grading rules	Species	Grade	Beams and stringers				Joist and plank				Posts and timbers		Stress in compression perpendicular to grain	Modulus of elasticity
			Stress in extreme fiber		Stress in horizontal shear		Stress in extreme fiber		Stress in horizontal shear		Compression parallel to grain			
			Strength ratio	Stress	Strength ratio	Stress	Strength ratio	Stress	Strength ratio	Stress	Strength ratio	Stress		
			Percent	*Lb. per sq. in.*	*Percent*	*Lb. per sq. in.*	*Percent*	*Lb. per sq. in.*	*Percent*	*Lb. per sq. in.*	*Percent*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*
California Redwood Association, San Francisco, Calif., Jan. 15, 1930.	Redwood	Prime structural [2]	88	1,494	88	82	83	1,707	88	82	88	1,245	267	1,200,000
		Select structural [2]	76	1,322	75	70	67	1,280	75	70	78	1,100		
		Heart structural [2]	68	1,150	60	56	57	1,024	60	56	70	1,000		
Northern Hemlock and Hardwood Manufacturers' Association, Oshkosh, Wis., Nov. 28, 1932.	Eastern Hemlock	Select structural	75	1,100	75	70	67	1,100	75	70	75	700	300	1,100,000
Southern Pine Association, New Orleans, La., Sept. 1, 1932.	Longleaf pine [3]	Select structural	86	2,000	67	125	(4)		(4)		86	1,450	380	1,600,000
		Prime structural	76	1,800	67	125	67	1,800	67	125	77	1,300		
		Merchantable structural	69	1,600	67	125	65	1,600	67	125	70	1,200		
		Structural square edge and sound.	69	1,600	67	125	65	1,600	56	125	70	1,200		
		No. 1 structural	60	1,400	56	105	(4)		(4)		60	1,000		
	Shortleaf pine [3]	Dense select structural	86	2,000	67	125	(4)		(4)		86	1,450	380	1,600,000
		Dense structural	76	1,800	67	125	69	1,800	67	125	77	1,300		
		Dense structural square edge and sound.	69	1,600	67	125	65	1,600	67	125	70	1,200		
		Dense No. 1 structural [5]	------	1,200	------	125	57	1,200	56	125	------	850		
Southern Cypress Manufacturers' Association, Jacksonville, Fla., May 11, 1933.	Southern cypress	Select structural	75	1,300	75	100	67	1,300	75	100	75	1,100	300	1,200,000
		Select structural heart	75	1,300	75	100	67	1,300	75	100	75	1,100		
		Common structural	60	1,040	60	80	57	1,040	60	80	60	880		
		Common structural heart	60	1,040	60	80	57	1,040	60	80	60	880		
West Coast Lumbermen's Association, Seattle, Wash., Aug. 30, 1932.	Douglas fir (coast region).	Select structural [2 6]	76	1,600	75	100	69	1,600	75	120	80	1,200	345	1,600,000
		Dense select structural [6 7]	76	1,800	75	120	69	1,800	75	140	80	1,300	380	

[1] These stresses agree closely with the values computed from the strength ratios given in this table and the basic stresses of table 20 by the procedure given on p. 105 except that the horizontal shear stresses for joist and plank of select structural and dense select structural Douglas fir, structural square edge and sound longleaf pine, and dense no. 1 structural shortleaf pine are about 30 percent higher; other horizontal shear stresses for longleaf and shortleaf pines and Douglas fir are about 10 percent higher.

[2] Close-grain material required.

[3] Dense material required in all grades. Cluster knots and knots in groups not prohibited. Material up to 5 inches thick graded as joist and plank.

[4] Joist and plank are not described under these grade names.

[5] Admits in beams and stringers and in posts and timbers unsound knots up to 1½ inches in diameter and pin wormholes.

[6] In beams and stringers and in joists and planks knots are restricted throughout the length as required for the middle third of the length. No shakes permitted.

[7] Requires dense material.

would be expected with loads 50 percent in excess of those computed from the tabulated stress values or with decrease in strength of the timber through decay or other deterioration to two-thirds its original value, but numerous failures are to be expected if such loads are doubled or if the strength of the timber decreases to one-half its original strength.

TABLE 19.—*Strength ratios corresponding to the grade examples of American lumber standards*

Designation	Strength ratios				
	Beams and stringers		Joist and plank		Posts and timbers
	Stress in extreme fiber	Horizontal shear	Stress in extreme fiber	Horizontal shear	Compression parallel to grain
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Select	75	75	66⅔	75	75
Common	60	60	56⅔	60	60

For loads that will remain on the structure for a short time only, somewhat higher working stresses may be used. For example, in designing for wind loads in addition to dead and live loads, the working stresses may be increased 50 percent, provided the resulting structural members are not smaller than those designed for dead and live load alone.

The stresses given may be used without regard to impact, unless the impact stress exceeds the allowable live-load stress.

The working stresses for compression parallel to grain apply to posts, columns, and struts whose unsupported length does not exceed 11 times the least dimension of the cross section. For more slender members suitable column formulas (p. 162) are to be used.

The compression-perpendicular-to-grain values listed apply to bearings 6 inches or more in length located anywhere in the length of a timber and to bearings of any length at the ends of beams or other members. For bearings shorter than 6 inches located 3 inches or more from the end of a timber the stresses may be increased in accordance with the following factors:

Length of bearings (inches):	*Factor*
½	1.85
1	1.60
1½	1.45
2	1.30
3	1.15
4	1.10
6 or more	1.00

For stress under a washer the same factor may be taken as for a bearing whose length equals the diameter of the washer.

Shear stresses 50 percent in excess of the basic stresses given in column 5 of table 20 are suggested for use in designing details of joints.

The tensile strength of wood is greater than the modules of rupture as obtained from bending tests. Hence stresses in the body of a tension member fully equal to those given for fiber stress in bending in table 18 or others obtained according to procedure on page 106 are justified. However, the design load for a wooden tension member is usually determined by the strength of the attachment to other parts of the structure. For allowable tensile stresses at the critical sections of joints see discussion on bolted joints (p. 130) and on timber connectors (p. 136).

TABLE 20.—*Basic stresses for clear material* [1]

[All values are in pounds per square inch and are for material that is continuously dry or continuously wet]

Species	Extreme fiber in bending	Compression perpendicular to grain [2]	Compression parallel to grain L/d=10	Maximum horizontal shear	Modulus of elasticity
(1)	(2)	(3)	(4)	(5)	(6)
Ash, black	1,333	300	866	120	1,100,000
Ash, commercial white	1,866	500	1,466	167	1,500,000
Beech	2,000	500	1,600	167	1,600,000
Birch, sweet and yellow	2,000	500	1,600	167	1,600,000
Cedar, Alaska	1,466	250	1,066	120	1,200,000
Cedar, northern and southern white	1,000	175	733	93	800,000
Cedar, Port Orford	1,466	250	1,200	120	1,200,000
Cedar, western red	1,200	200	933	106	1,000,000
Chestnut	1,266	300	1,066	120	1,000,000
Cypress, southern	1,733	300	1,466	133	1,200,000
Douglas fir, coast region	2,000	325	1,466	120	1,600,000
Douglas fir, coast region, close-grained	2,133	345	1,565	120	1,600,000
Douglas fir, Rocky Mountain region	1,466	275	1,066	113	1,200,000
Douglas fir, dense, all regions	2,333	380	1,711	140	1,600,000
Elm, American and slippery [3]	1,466	250	1,066	133	1,200,000
Elm, rock	2,000	500	1,600	167	1,300,000
Fir, balsam	1,200	150	933	93	1,000,000
Fir, commercial white	1,466	300	933	93	1,100,000
Gum, black and red	1,466	300	1,066	133	1,200,000
Hemlock, eastern	1,466	300	933	93	1,100,000
Hemlock, western [4]	1,733	300	1,200	100	1,400,000
Hickory, true and pecan	2,533	600	2,000	187	1,800,000
Larch, western	[5] 1,600	325	1,466	133	1,300,000
Maple, sugar and black [6]	2,000	500	1,600	167	1,600,000
Oak, commercial red and white	1,866	500	1,333	167	1,500,000
Pine, western white,[7] northern white, ponderosa, and sugar	1,200	250	1,000	113	1,000,000
Pine, Norway	1,466	300	1,066	113	1,200,000
Pine, southern yellow [8]	2,000	325	1,466	146	1,600,000
Pine, southern yellow, dense	2,333	380	1,711	171	1,600,000
Redwood	1,600	250	1,333	93	1,200,000
Redwood, close-grained	1,707	267	1,422	93	1,200,000
Spruce, Engelmann	1,000	175	800	93	800,000
Spruce, red, white, and Sitka	1,466	250	1,066	113	1,200,000
Tamarack	1,600	300	1,333	126	1,300,000
Tupelo	1,466	300	1,066	133	1,200,000

[1] Basic stresses are for determining design or working stresses according to the grade of timber and conditions of exposure.

[2] For material that is continuously wet take 70 percent of these values.

[3] Sold as white elm or soft elm.

[4] Also sold as west coast hemlock.

[5] In setting up basic working stresses consideration has been given to results of tests on small clear specimens and to tests on full-sized timbers of the species when the latter are available. That the value for stress in extreme fiber of western larch ought to be higher than that listed here is indicated by tests of small specimens but is not confirmed by available tests on structural sizes.

[6] Sold as hard maple.

[7] Also sold as Idaho white pine.

[8] Also sold as longleaf or shortleaf southern pine.

BASIC STRESSES FOR CLEAR WOOD IN STRUCTURAL SIZES

The values listed in table 20 are basic stresses for material which is free of defects that affect the strength and which is used under such conditions that no deterioration will occur. They are termed

"basic" because they are the working-stress values for pieces of timber having a strength ratio of 100 percent. In deriving them, allowances have been made for the variability of the strength of clear wood and for the effect of long-continued stress, and a factor of safety has been introduced. For example, in deriving the basic stresses in extreme fiber in bending the average ultimate strength values as found from tests of clear wood in the green condition have been reduced by one-fourth to allow for the effect of variability and multiplied by nine-sixteenths to allow for the effect of long-continued stress and then divided by one and two-thirds as a factor of safety. Mutually consistent and equitable stress values cannot be derived solely by systematic computation from recorded data on strength and the basic stresses of table 20 therefore vary from systematically computed values according to favorable or unfavorable behavior of structural timbers of the species as observed in tests and under actual service conditions.

DETERMINATION OF WORKING STRESSES

TIMBER CONTINUOUSLY DRY OR CONTINUOUSLY WET

The basic values listed in table 20 afford a basis for the computation of working stresses. Inasmuch as factors of safety have been applied in their derivation, multiplication of the values in table 20 by the strength ratio or ratios of the grade give, with certain exceptions pointed out later, the working stresses for material that is to remain either dry or saturated.

These working stresses may be obtained as follows:

(1) If the strength ratio is unknown, it may be found by comparing the description of the grade with the specification requirements for structural grades as given on pages 108 to 117.

(2) Multiply the basic stresses in extreme fiber in bending, horizontal shear, and compression parallel to grain by the strength ratio. Stress in compression perpendicular to grain and modulus of elasticity are not varied with grade.

(3) For material 4 inches or less in thickness to be used where continuously dry, the strength ratio for stress in extreme fiber, or for stress in compression parallel to grain, is first increased by one-half of its excess over 50 percent. If, for example, the strength ratio for stress in extreme fiber in bending for a grade of joist and plank is 66⅔ percent, and the material is to be used where it will be continuously dry, the working stress is 75 percent of the basic stress for the species.

(4) Compression perpendicular to grain values for a continuously wet conditions should be 70 percent of the basic stress (table 20) for the species.

TIMBERS USED UNDER CONDITIONS FAVORABLE TO DECAY

Timber that remains dry, such as that in most covered structures, or that is constantly wet, such as parts that are below permanent water level, is not subject to decay, and stresses derived as outlined in the preceding paragraph apply. Under other circumstances timber is, in varying degrees, subject to decay, and allowance for the resulting deterioration is advisable. This may be accomplished by in-

creasing the sizes of members either arbitrarily or through the lowering of design stresses.

Decay progresses most rapidly in places that are warm, humid, damp, or poorly ventilated and varies to moderate or very slight in places where lower temperatures prevail or where occasional dampness or wetting is offset by good ventilation that leads to quick drying.

Table 21 presents suggested average ratios among stresses for no decay hazard, moderate decay hazard, and severe decay hazard. The magnitude of the allowance to be made for deterioration from decay is a moot question, and the ratios of table 21 are therefore to be taken only as a general guide and as applicable to species of average durability. They should be modified in accordance with such factors as the natural resistance of the heartwood to decay (p. 41), the proportion of sapwood permitted in the timber, the expected life of the structure or part, the frequency and thoroughness of inspection, and the cost of making replacements. In any instance in which the decay hazard is obviously high, treated material or the heartwood of a highly decay-resistant species should be employed unless the hazard can be reduced by attention to such features as drainage and ventilation. Nondurable woods should never be used where there is a decay hazard. In all instances design details should be such as to minimize the danger of decay (p. 252).

TABLE 21.—*Average ratios among stresses for 3 decay hazards*

Kind of stress	Decay hazard		
	None	Moderate	Severe
	Percent	*Percent*	*Percent*
Stress in extreme fiber in bending	100	85	71
Stress in compression perpendicular to grain	[1] 100	70	58
Stress in compression parallel to grain	100	92	78
Stress in horizontal shear in beams	100	100	100
Modulus of elasticity	100	100	100

[1] Value applicable only to material continuously dry; for material continuously wet the value is 70 percent

The following procedure is suggested for obtaining appropriate working stresses where a decay hazard exists:

(1) If the strength ratio is unknown, it may be found by comparing the description of the grade with the specification requirements for structural grades as given on pages 108 to 117.

(2) If the wood is untreated, estimate (with the help of table 21 and the relative natural resistance of the species to decay (p. 41)) the appropriate ratio for the species and condition of service.

(3) Multiply the basic stress as given in table 20 by the appropriate ratio as determined under (2).

(4) For stress in extreme fiber in bending, stress in horizontal shear, or stress in compression parallel to the grain, multiply by the strength ratio for the grade as determined under (1).

TREATED MATERIAL

In the treatment of timber, reductions in strength sufficient to merit consideration in connection with working stresses result from the temperature, heating periods, and pressures involved in the

preparation of material and the injection of preservatives as currently practiced. Such reductions range in amount up to 25 percent, or more in occasional instances, for stress in extreme fiber in bending. Strengths in compression parallel and perpendicular to grain are ordinarily less affected, and modulus of elasticity very little. The effect on resistance to horizontal shear can be estimated by inspection for shakes and checks subsequent to treatment.

The harmful effects may be reduced and minimized by restricting temperatures, heating periods, and pressures as much as is consistent with proper absorption and penetration of preservative (p. 278). With these restrictions in treatment losses as large as previously mentioned are much less likely.

In view of the fact that proper preservative treatment so effectively reduces the damage caused by destructive organisms it seems permissible to disregard a reasonable loss in strength and to use, with treated material, the working stresses that would apply if the species were naturally durable. The ratio of stresses for a naturally durable wood used under conditions of no-, moderate-, and high-decay hazard may be obtained from information given on page 107 and table 21.

SPECIFICATION REQUIREMENTS FOR STRUCTURAL GRADES

Information is presented here for use in drafting descriptions of timber grades or for determining the strength ratios of a grade or of a timber from its description.

CLASSIFICATION OF TIMBERS

The effects of knots, deviations of grain, shakes, and checks on the strength of a timber vary with the loading to which the piece is subjected. Also the effect of seasoning varies with the size of the timber. Consequently, efficiency in grading necessitates classifying timbers according to their size and use. Such a classification is as follows:

Beams and stringers.—Large pieces (nominal dimensions 5 by 8 inches and up) of rectangular cross section graded with respect to their strength in bending when loaded on the narrow face.

Joist and plank.—Pieces (nominal dimensions 2 to 4 inches in thickness by 4 inches and wider) of rectangular cross section graded with respect to their strength in bending when loaded either on the narrow face as joist or on the wide face as plank.

Posts and timbers.—Pieces of square or approximately square cross section, 4 by 4 inches and larger, in nominal dimension, graded primarily for use as posts or columns but adapted to miscellaneous uses in which strength in bending is not especially important.

ACTUAL DIMENSIONS

In accordance with American lumber standards, rough (unsurfaced) pieces shall be sawn full to nominal dimension except that occasional slight variation in sawing is permissible. At no part of the length shall any piece because of such variation be more than three-sixteenth inch under the nominal dimension when this dimension is 3 to 7 inches, inclusive, nor more than one-fourth inch under the nominal dimension when this dimension is 8 inches or greater. The actual thickness of nominal 2-inch material shall not be less

than 1⅞ inches at any part of the length. Furtner, no shipment shall contain more than 20 percent of pieces of minimum dimension.

Surfacing of beams and stringers, whether on one or both of a pair of opposite faces, shall leave the finished size not more than one-half inch under the nominal dimension.

Surfacing of joist and plank, whether on one or both of a pair of opposite faces, shall leave the finished size not more than three-eighths inch under the nominal dimension when this dimension is 7 inches or less and not more than one-half inch under the nominal dimension when this dimension is 8 inches or greater.

Surfacing of posts and timbers, whether on one or both of a pair of opposite faces, shall leave the finished size not more than three-eighths inch under the nominal dimensions when this dimension is 4 inches and not more than one-half inch under the nominal dimension when this dimension is 5 inches or greater.

QUALITY OF WOOD

No piece of exceptionally light weight for the species is permitted.[23]

DECAY

Only pieces consisting of sound wood, free from any form of decay, including firm red heart and dote, are acceptable.

SLOPE OF GRAIN

Table 22 gives the strength ratios corresponding to various slopes of grain. Slope of grain is to be measured over a distance sufficiently great to define the general slope disregarding short local deviations (p. 64).

TABLE 22.—*Strength ratios corresponding to various slopes of grain*

[Beams and stringers or joist and plank—strength ratio for stress in extreme fiber in bending. Posts and timbers—strength ratio for stress in compression parallel to grain]

Slope of grain	Strength ratio		Slope of grain	Strength ratio	
	Beams and stringers or joist and plank	Posts and timbers		Beams and stringers or joist and plank	Posts and timbers
	Percent	*Percent*		*Percent*	*Percent*
1 in 6	----------	50–56	1 in 15	74–76	87–100
1 in 8	50–53	56–66	1 in 16	76–80	----------
1 in 10	53–61	66–74	1 in 18	80–85	----------
1 in 12	61–69	74–82	1 in 20	85–100	----------
1 in 14	69–74	82–87			

The limitations given for beams and stringers and joist and plank in table 22 apply only within the middle half [24] of the length of the piece; the slope in other parts is disregarded. The limitations for posts and timbers apply throughout the length of the piece.

[23] In certain species material selected for close grain or for density may be specified. Definitions of dense and close grain as applied to Douglas fir and southern pines are included in Simplified Practice Recommendation R16–29 and in publications of the American Society for Testing Materials and the American Railway Engineering Association.

[24] The limitations herein stated for the sizes of knots in the middle third of the length and for slope of grain in the middle one-half of the length of beams and stringers or joists and planks assume that such pieces of timber will be used on single spans. They should be applied to the middle two-thirds of the length of pieces to be used over double spans and to the entire length of pieces to be used over three or more spans.

KNOTS

Sizes of knots permissible in grades having various strength ratios are determined according to tables on pages 112 to 114 supplemented by the following definitions, explanations, and limitations.

Cluster knots and knots in groups are not permitted.

Knot holes and holes from causes other than knots are measured and limited as provided for knots.

Measurement of Knots

BEAMS AND STRINGERS

On a narrow face of the piece the size of a knot (fig. 10) is taken as its width between lines enclosing the knot and parallel to the edges of the piece (p. 112); except that when a knot on a narrow face extends into the adjacent one-fourth of the width of a wide face its least dimension is taken as its size.

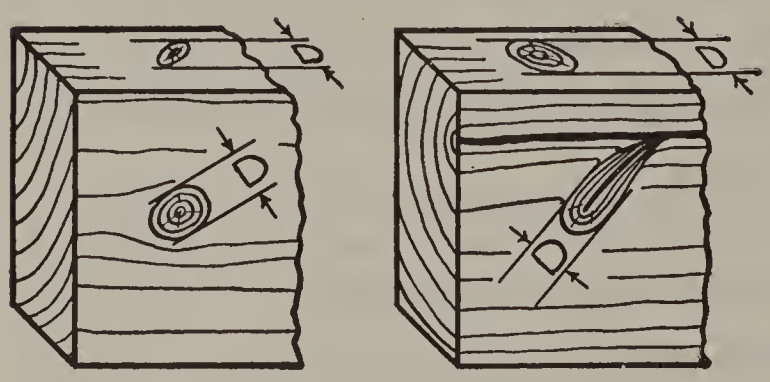


FIGURE 10.—Measurement of knots in beams and stringers.

On a wide face the size of a knot is taken at its smallest diameter.

At the edges of wide faces knots are limited to the same sizes as on the narrow faces of the same piece.

The sizes of knots on narrow faces and at edges of wide faces may increase proportionately from the size permitted in the middle third [25] of the length (p. 112) to twice that size at the ends of the piece (fig. 11) except that the size of no knot shall exceed the size permitted along the center line of the wide face (p. 113).

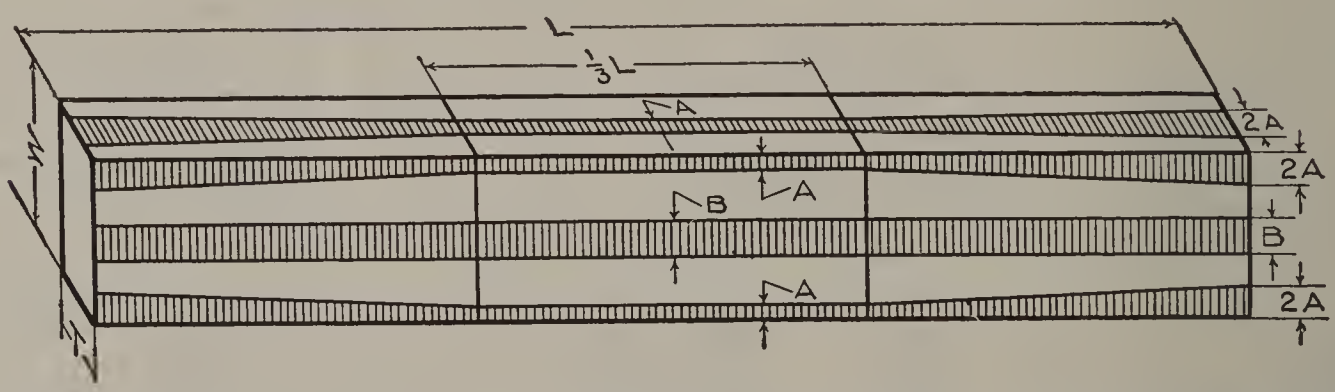


FIGURE 11.—Maximum size of knots permitted in various parts of beams and stringers: *A*, Maximum size on narrow face or edge of wide face, middle third of length with a gradual increase to 2*A* at ends of piece; *B*, maximum size at center line of wide face; *L*, length; *W*, width; *T*, thickness.

The size of knots on wide faces may increase proportionately from the size permitted at the edge to the size permitted along the center line.

The sum of the sizes of all knots within the middle half of the length of any face measured as specified for the face under consideration shall not exceed four times the size of the largest knot allowed on that face.

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[25] See footnote 24, p. 109.

JOIST AND PLANK

On a narrow face of the piece, the size of a knot is taken as its width between lines parallel to the edges of the piece (fig. 12 *A*). The only knots measured on the narrow faces of a piece are those that do not show on the wide faces.

On a wide face the size of knot is taken as half the sum of its largest and smallest diameters (fig. 12, *A*) and the size of a spike knot is taken as half the sum of its length and greatest width.

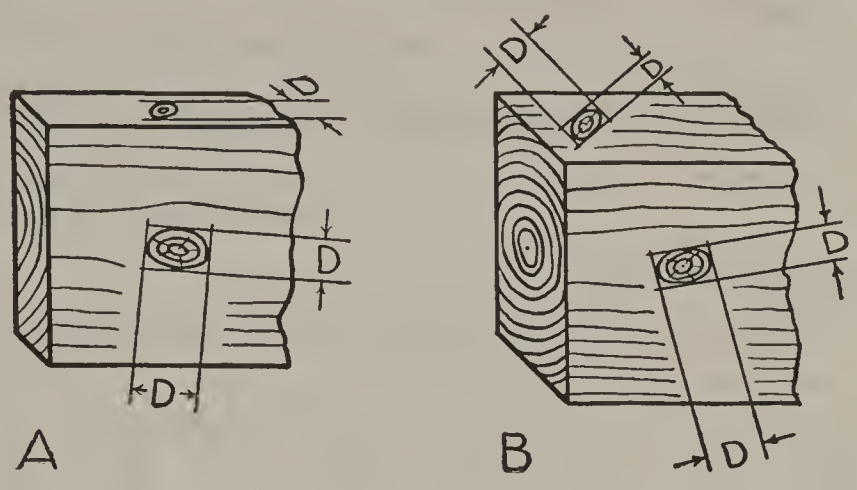


FIGURE 12.—Measurement of knots: *A*, On joist and plank; *B*, on posts and timbers.

The sizes of knots on narrow faces and at edges of wide faces may increase proportionately from the size permitted in the middle third [26] of the length (pp. 112 and 114) to twice that size at the ends of the piece.

The size of knots on wide faces may increase proportionately from the size permitted at the edge to the size permitted along the center line (p. 113).

The sum of the sizes of all knots within the middle half of the length of any face measured as specified for the face under consideration shall not exceed 4½ times the size of the largest knots allowed on that face.

POSTS AND TIMBERS

On any face the size of a knot is taken as half the sum of its largest and smallest diameter, and the size of a spike knot is taken as half the sum of its length and greatest width (fig. 12, *B*).

The sum of the sizes of all knots in any 6 inches of length of the piece is not permitted to exceed twice the maximum permissible size of knots. Two knots of maximum permissible size are not allowed in the same 6 inches of length on any face.

TABLES OF KNOT SIZES AND THEIR USE

The use of tables 23, 24, and 25, which give sizes of knots, is illustrated by the following example.[27] The sizes of knots permissible in a nominal 8 by 16 inch piece in a grade having a strength-ratio of 70 percent are desired. The smallest ratio in the column for 8-inch face in table 23 (narrow face) that equals or exceeds 70 percent is opposite 2⅛ inches in the size-of-knot column and a simi-

[26] See footnote 24, p. 109.

[27] The sizes of knots or shakes corresponding to various strength ratios when computed by definite rules involve decimals. A reasonable rule for changing these decimals to common fractions is to hold one fraction until the computed size of defects is two-thirds the way to the next fraction. Thus, when fractions differ by eights of an inch, only those greater than two, five, eight, eleven, fourteen, seventeen, twenty, or twenty-three twenty-fourths are rounded up to the next higher size. The equivalent of this conversion method is to subtract from each size of defect one-third the difference between successive sizes before computing the corresponding strength ratio. Tables 23 to 27, inclusive, have been computed on this basis, the difference between successive sizes being taken as one-eighth inch. For example, the strength ratios listed for a 3½-inch knot are those that actually would obtain for a size $3\frac{11}{24}$ inches. In view of the allowance thus introduced and the fact that nominal instead of actual widths of face have been used, the strength ratios in tables 23 to 27, inclusive, should be taken as maximums.

lar rate in the column for 16-inch face in table 24 (wide face) is opposite 4¼ inches. Hence, the permissible sizes are 2⅛ inches on the 8-inch face and 4¼ inches along the center line of the 16-inch face.

TABLE 23.—*Strength ratios for stress in extreme fiber in bending corresponding to various combinations of size of knot and width of face*

[Beams and stringers—narrow face or edge of wide face within middle third[1] of length of piece. Joist and plank—narrow face within middle third[1] of length of piece]

Size of knot (inches)	Strength ratio when nominal width of face is—									
	2 inches	3 inches	4 inches	5 inches	6 inches	8 inches	10 inches	12 inches	14 inches	16 inches
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
¼	90	93	95	96	96	97	97	97	98	98
⅜	83	89	92	93	94	95	96	96	96	97
½	77	85	88	91	92	93	94	95	95	95
⅝	71	81	85	88	90	92	92	93	94	94
¾	65	76	82	86	88	90	91	92	92	93
⅞	58	72	79	83	86	88	89	90	91	91
1	52	68	76	81	84	86	88	89	89	90
1⅛		64	73	78	82	84	86	87	88	89
1¼		60	70	76	80	83	84	86	87	88
1⅜		56	67	73	78	81	83	84	85	86
1½		51	63	71	76	79	81	83	84	85
1⅝			60	68	74	77	80	81	83	84
1¾			57	66	71	75	78	80	81	83
1⅞			54	63	69	73	76	78	80	81
2			51	61	67	72	75	77	79	80
2⅛				58	65	70	73	75	77	79
2¼				56	63	68	71	74	76	77
2⅜				53	61	66	70	72	74	76
2½				51	59	64	68	71	73	75
2⅝					57	63	67	70	72	74
2¾					55	61	65	68	70	72
2⅞					53	59	63	67	69	71
3					51	57	62	65	68	70
3⅛						55	60	64	66	68
3¼						54	59	62	65	67
3⅜						52	57	61	64	66
3½						50	55	59	62	65
3⅝							54	58	61	63
3¾							52	56	59	62
3⅞							50	55	58	61
4								53	57	60
4⅛								52	55	58
4¼								50	54	57
4⅜									53	56
4½									51	54
4⅝									50	53
4¾										52
4⅞										51

[1] The limitations assume that such pieces of timber will be used on single spans. They should be applied to the middle ⅔ of the length of pieces to be used over double spans and to the entire length of pieces to be used over 3 or more spans.

SHAKES AND CHECKS

BEAMS AND STRINGERS OR JOIST AND PLANK

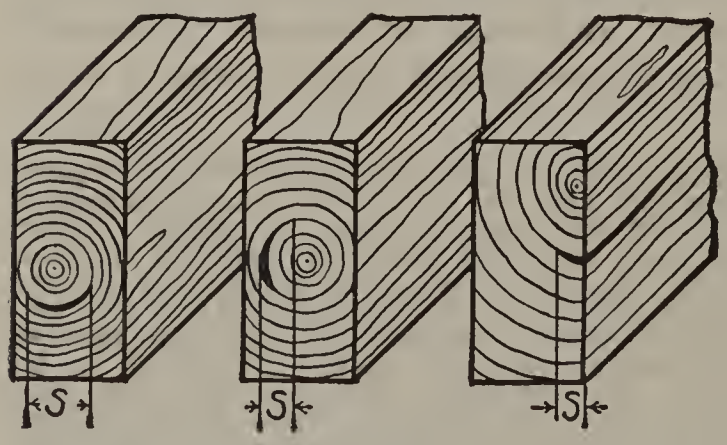


FIGURE 13.—Measurement of shakes in beams and stringers or joist and plank.

Limitations for shakes in beams and stringers and in joist and plank are indicated by table 26.

Shakes are measured at the ends of the piece (fig. 13). In beams and stringers and joist and plank only those within the middle half of the height of the piece are considered. (Height equals width of wide

face.) The size of a shake is the distance between lines enclosing the shake and parallel to the wide faces of the piece. The permissible size is determined by the width of the narrow face of the piece.

TABLE 24.—*Strength ratios corresponding to various combinations of size of knot and width of face*

[Beams and stringers or joist and plank—along center line of wide face at any point in the length of the piece. Strength ratios for stress in extreme fiber in bending. Posts and timbers—at any point on any face. Strength ratios for stress in compression parallel to grain]

Size of knot (inches)	Strength ratio when nominal width of face is—											
	4 inches	5 inches	6 inches	8 inches	10 inches	12 inches	14 inechs	16 inches	18 inches	20 inches	22 inches	24 inches
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1/4	95	96	96	97	98	98	98	98	99	99	99	99
1/2	88	91	92	94	95	96	96	97	97	97	97	97
3/4	82	86	88	91	93	94	94	95	95	95	96	96
1	76	81	84	88	90	92	93	93	93	94	94	94
1 1/4	70	76	80	85	88	90	91	91	92	92	93	93
1 1/2	63	71	76	82	85	88	89	89	90	91	91	91
1 3/4	57	66	71	79	83	86	87	88	88	89	89	90
2	51	61	67	75	80	84	85	86	87	87	88	88
2 1/4	-------	56	63	72	78	82	83	84	85	86	86	87
2 1/2	-------	51	59	69	75	79	81	82	83	84	85	85
2 3/4	-------	-------	55	66	73	77	79	80	82	82	83	84
3	-------	-------	51	63	70	75	77	79	80	81	82	83
3 1/4	-------	-------	-------	60	68	73	75	77	78	79	80	81
3 1/2	-------	-------	-------	57	65	71	73	75	76	78	79	80
3 3/4	-------	-------	-------	54	63	69	71	73	75	76	77	78
4	-------	-------	-------	50	60	67	69	71	73	74	76	77
4 1/4	-------	-------	-------	-------	58	65	67	70	71	73	74	75
4 1/2	-------	-------	-------	-------	55	63	66	68	70	71	73	74
4 3/4	-------	-------	-------	-------	53	61	64	66	68	70	71	72
5	-------	-------	-------	-------	50	59	62	64	66	68	70	71
5 1/4	-------	-------	-------	-------	-------	57	60	62	65	66	68	69
5 1/2	-------	-------	-------	-------	-------	54	58	61	63	65	66	68
5 3/4	-------	-------	-------	-------	-------	52	56	59	61	63	65	66
6	-------	-------	-------	-------	-------	50	54	57	59	61	63	65
6 1/4	-------	-------	-------	-------	-------	-------	52	55	58	60	62	63
6 1/2	-------	-------	-------	-------	-------	-------	50	53	56	58	60	62
6 3/4	-------	-------	-------	-------	-------	-------	-------	52	54	57	59	60
7	-------	-------	-------	-------	-------	-------	-------	50	53	55	57	59
7 1/4	-------	-------	-------	-------	-------	-------	-------	-------	51	53	56	57
7 1/2	-------	-------	-------	-------	-------	-------	-------	-------	-------	52	54	56
7 3/4	-------	-------	-------	-------	-------	-------	-------	-------	-------	50	53	55
8	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	51	53
8 1/4	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	52
8 1/2	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	50

Checks and splits are limited in the same way as shakes. The following limitations apply to both ends but only within the middle half of the height of the piece and within three times the height from the end. (Height equals width of wide face.) The size of checks within this portion of the piece shall be taken as their estimated area, along the horizontal section showing maximum area, divided by three times the height of the piece. When checks on two parallel faces are opposite or approximately so, the sum of their sizes is taken. The sum of the sizes of shakes, checks, and/or splits shall not exceed the permissible size of shake.

Checks extending entirely across the end within the middle half of the height shall not extend into the piece at the center of the width of the end a distance greater than the size of the allowable shake.

POSTS AND TIMBERS

Limitations for shakes in posts and timbers are indicated in table 27. Shakes do not greatly affect the strength of members subjected

to longitudinal compression. Their effect on appearance and the opportunity they afford for the start of decay form the principal basis for the limitations given in table 27.

TABLE 25.—*Strength ratios for stress in extreme fiber in bending corresponding to various combinations of size of knot and width of face*

[Joist and plank—at edge of wide face within middle third [1] of length of piece]

Size of knot (inches)	Strength ratio when nominal width of face is—										
	4 inches	6 inches	8 inches	10 inches	12 inches	14 inches	16 inches	18 inches	20 inches	22 inches	24 inches
	Per-cent	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*
1/4	90	93	95	96	97	97	97	97	97	97	98
3/8	84	89	92	93	94	95	95	95	96	96	96
1/2	78	85	89	91	92	93	93	94	94	94	95
5/8	73	81	86	89	90	91	92	92	93	93	93
3/4	68	78	83	86	88	89	90	91	91	91	92
7/8	63	74	80	84	87	88	88	89	89	90	90
1	58	71	77	82	85	86	87	87	88	89	89
1 1/8	53	67	75	79	83	84	85	86	86	87	88
1 1/4	-------	64	72	77	81	82	83	84	85	86	86
1 3/8	-------	60	69	75	79	80	82	83	83	84	85
1 1/2	-------	57	67	73	77	79	80	81	82	83	84
1 5/8	-------	53	64	71	75	77	78	80	81	81	82
1 3/4	-------	51	62	69	74	75	77	78	79	80	81
1 7/8	-------	-------	59	67	72	74	75	77	78	79	80
2	-------	-------	57	65	70	72	74	75	76	77	78
2 1/8	-------	-------	55	63	68	70	72	74	75	76	77
2 1/4	-------	-------	52	61	67	69	71	72	73	75	76
2 3/8	-------	-------	50	59	65	67	69	71	72	73	74
2 1/2	-------	-------	-------	57	63	66	68	69	71	72	73
2 5/8	-------	-------	-------	55	62	64	66	68	69	71	72
2 3/4	-------	-------	-------	53	60	63	65	66	68	69	71
2 7/8	-------	-------	-------	51	58	61	63	65	67	68	69
3	-------	-------	-------	50	57	60	62	64	65	67	68
3 1/8	-------	-------	-------	-------	55	58	60	62	64	66	67
3 1/4	-------	-------	-------	-------	54	57	59	61	63	64	66
3 3/8	-------	-------	-------	-------	52	55	58	60	62	63	65
3 1/2	-------	-------	-------	-------	51	54	56	58	60	62	63
3 5/8	-------	-------	-------	-------	-------	52	55	57	59	61	62
3 3/4	-------	-------	-------	-------	-------	51	54	56	58	60	61
3 7/8	-------	-------	-------	-------	-------	50	52	55	57	58	60
4	-------	-------	-------	-------	-------	-------	51	53	55	57	59
4 1/8	-------	-------	-------	-------	-------	-------	50	52	54	56	58
4 1/4	-------	-------	-------	-------	-------	-------	-------	51	53	55	57
4 3/8	-------	-------	-------	-------	-------	-------	-------	50	52	54	55
4 1/2	-------	-------	-------	-------	-------	-------	-------	-------	51	53	54
4 5/8	-------	-------	-------	-------	-------	-------	-------	-------	50	51	53
4 3/4	-------	-------	-------	-------	-------	-------	-------	-------	-------	50	52
4 7/8	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	51
5	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	50

[1] The limitations assume that such pieces of timber will be used on single spans. They should be applied to the middle two-thirds of the length of pieces to be used over double spans and to the entire length of pieces to be used over 3 or more spans.

Shakes are measured at the ends of the piece (fig. 14). The size of a shake is the distance between the maximum spaced pair of lines exactly enclosing the shake and parallel to two opposite faces.

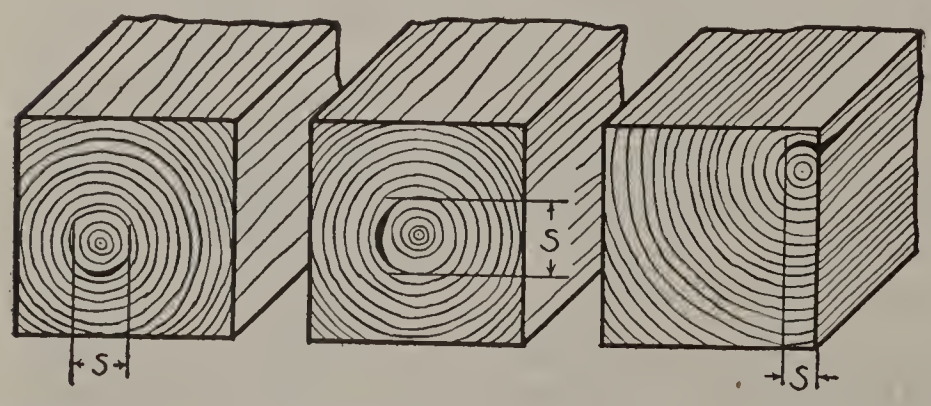


FIGURE 14.—Measurement of shakes in posts and timbers.

Checks and splits are limited in the same way as shakes. The size of checks within three times the width of the piece

from either end shall be taken as their estimated area, along the longitudinal section showing maximum area, divided by three times the width of the piece. The sum of the sizes of shakes, checks, and/or splits shall not exceed the permissible size of shake.

Checks extending entirely across the end shall not extend into the piece, at the center of the width of the end, a distance greater than the size of the allowable shake.

Only widths of end up to 12 inches are listed in table 27. Sizes of shakes for wider ends can be found by addition. For example, the sizes in green material for widths of 6 and 8 inches and for a strength ratio of 60 percent are found by interpolation in table 27 as 3⅛ and 4⅛ inches, respectively. Then the allowable size for a width of 14 inches is 7¼ inches.

TABLE 26.—*Strength ratios for stress in horizontal shear corresponding to various combinations of size of shake and width of end of piece*

[Beams and stringers or joist and plank]

GREEN MATERIAL

Size of shake (inches)	Strength ratio when nominal width of end of piece is—									
	2 inches	3 inches	4 inches	5 inches	6 inches	8 inches	10 inches	12 inches	14 inches	16 inches
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
¼	90	93	95	96	96	97	98	98	98	99
⅜	83	89	92	93	94	96	97	97	98	98
½	77	85	88	91	92	94	95	96	97	97
⅝	71	81	85	88	90	93	94	95	96	96
¾	65	76	82	86	88	91	93	94	95	96
⅞	58	72	79	83	86	90	92	93	94	95
1	52	68	76	81	84	88	90	92	93	94
1⅛		64	73	78	82	86	89	91	92	93
1¼		60	70	76	80	85	88	90	91	92
1⅜		56	67	73	78	83	87	89	90	92
1½		51	63	71	76	82	85	88	90	91
1⅝			60	68	74	80	84	87	89	90
1¾			57	66	71	79	83	86	88	89
1⅞			54	63	69	77	82	85	87	88
2			51	61	67	75	80	84	86	88
2⅛				58	65	74	79	83	85	87
2¼				56	63	72	78	82	84	86
2⅜				53	61	71	77	81	83	85
2½				51	59	69	75	79	82	85
2⅝					57	68	74	78	81	84
2¾					55	66	73	77	81	83
2⅞					53	65	72	76	80	82
3					51	63	70	75	79	81
3¼						60	68	73	77	80
3½						57	65	71	75	78
3¾						54	63	69	73	77
4						50	60	67	72	75
4¼							58	65	70	74
4½							55	63	68	72
4¾							53	61	66	71
5							50	59	65	69
5¼								57	63	67
5½								54	61	66
5¾								52	59	64
6								50	57	63
6¼									56	61
6½									54	60
6¾									52	58
7									50	56
7¼										55
7½										53
7¾										52
8										50

TABLE 26.—*Strength ratios for stress in horizontal shear corresponding to various combinations of size of shake and width of end of piece*—Con.

SEASONED MATERIAL

Size of shake (inches)	Strength ratio when nominal width of end of piece is—									
	2 inches	3 inches	4 inches	5 inches	6 inches	8 inches	10 inches	12 inches	14 inches	16 inches
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1/4	100	100	100	100	100	100	100	100	100	100
3/8	94	100	100	100	100	100	100	100	100	100
1/2	87	95	100	100	100	100	100	100	100	100
5/8	80	91	96	99	100	100	100	100	100	100
3/4	73	86	93	97	99	100	100	100	100	100
7/8	66	81	89	94	97	100	100	100	100	100
1	59	77	85	91	94	99	100	100	100	100
1 1/8	52	72	82	88	92	97	100	100	100	100
1 1/4		67	78	85	90	95	99	100	100	100
1 3/8		62	75	82	87	94	97	100	100	100
1 1/2		58	71	80	85	92	96	99	100	100
1 5/8		53	68	77	83	90	95	98	100	100
1 3/4			64	74	80	88	93	96	99	100
1 7/8			61	71	78	87	92	95	98	100
2			57	68	76	85	90	94	97	99
2 1/8			54	66	73	83	89	93	96	98
2 1/4			50	63	71	81	88	92	95	97
2 3/8				60	69	80	86	91	94	96
2 1/2				57	66	78	85	89	93	95
2 5/8				54	64	76	83	88	92	94
2 3/4				52	62	74	82	87	91	93
2 7/8					59	73	81	86	90	93
3					57	71	79	85	89	92
3 1/4					52	67	76	82	87	90
3 1/2					48	64	74	80	85	88
3 3/4						60	71	78	83	86
4						57	68	75	81	85
4 1/4						53	65	73	79	83
4 1/2						50	62	71	77	81
4 3/4							59	68	75	79
5							57	66	73	78
5 1/4							54	64	71	76
5 1/2							51	61	69	74
5 3/4								59	67	72
6								57	65	71
6 1/4								54	63	69
6 1/2								52	61	67
6 3/4								50	59	65
7									57	64
7 1/4									55	62
7 1/2									53	60
7 3/4									51	58
8										56
8 1/4										55
8 1/2										53
8 3/4										51
9										49

WANE

The following tabulation gives widths of wane permissible in grades having various strength ratios. It applies to beams and stringers, joists and planks, or posts and timbers.

Fraction of width of face occupied by width of wane:	*Strength ratio of grade*
1/4	50 percent up to and including 60 percent.
1/5	Above 60 percent up to and including 66 percent.
1/6	Above 66 percent up to and including 75 percent.
1/8	Above 75 percent up to and including 87 percent.
1/10	Above 87 percent.

The schedule of permissible sizes of wane has been made to conform with usual practice in grading although in some instances more strict limitations are imposed because of appearance or for other rea-

sons. Undue importance is often attached to wane, but its actual effects are much less than is implied. For example, the loss in strength due to wane one-fourth the width of two adjacent faces of a beam is only about 9 percent; and if such wane extended the full length of a beam, the deflection of the beam under load would be only about 7 percent greater than if no wane existed. It is safe to assume that the percentage reduction in bending strength due to wane does not exceed three times the percentage reduction in area of cross section of the piece. Wane at the ends of beams is often undesirable because of the eccentric and reduced area available for bearing.

TABLE 27.—*Strength ratios for stress in compression parallel to grain corresponding to various combinations of size of shake and width of end of piece*

[Posts and timbers]

Size of shake (inches)	Strength ratio for green material having a nominal width of end of piece of—						Strength ratio for seasoned material having a nominal width of end of piece of—					
	4 inches	5 inches	6 inches	8 inches	10 inches	12 inches	4 inches	5 inches	6 inches	8 inches	10 inches	12 inches
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
¾	100	100	100	100	100	100	100	100	100	100	100	100
1	95	100	100	100	100	100	100	100	100	100	100	100
1¼	87	95	100	100	100	100	100	100	100	100	100	100
1½	79	89	95	100	100	100	92	100	100	100	100	100
1¾	72	82	89	98	100	100	84	95	100	100	100	100
2	64	76	84	94	100	100	76	88	97	100	100	100
2¼	56	70	79	90	97	100	68	82	91	100	100	100
2½	48	63	74	87	94	99	61	76	86	99	100	100
2¾	-------	57	69	83	91	97	53	70	81	95	100	100
3	-------	51	63	79	88	94	45	63	76	91	100	100
3¼	-------	-------	58	75	85	92	-------	57	71	87	97	100
3½	-------	-------	53	71	82	89	-------	51	65	83	94	100
3¾	-------	-------	48	67	79	86	-------	-------	60	80	91	99
4	-------	-------	-------	63	75	84	-------	-------	55	76	88	96
4¼	-------	-------	-------	59	72	81	-------	-------	50	72	85	94
4½	-------	-------	-------	55	69	79	-------	-------	-------	68	82	91
4¾	-------	-------	-------	51	66	76	-------	-------	-------	64	79	88
5	-------	-------	-------	-------	63	73	-------	-------	-------	60	75	86
5¼	-------	-------	-------	-------	60	71	-------	-------	-------	56	72	83
5½	-------	-------	-------	-------	57	68	-------	-------	-------	52	69	81
5¾	-------	-------	-------	-------	54	65	-------	-------	-------	48	66	78
6	-------	-------	-------	-------	50	63	-------	-------	-------	-------	63	75
6¼	-------	-------	-------	-------	-------	60	-------	-------	-------	-------	60	73
6½	-------	-------	-------	-------	-------	58	-------	-------	-------	-------	57	70
6¾	-------	-------	-------	-------	-------	55	-------	-------	-------	-------	54	68
7	-------	-------	-------	-------	-------	52	-------	-------	-------	-------	50	65
7¼	-------	-------	-------	-------	-------	50	-------	-------	-------	-------	-------	62
7½	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	60
7¾	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	57
8	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	55
8¼	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	52
8½	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	49

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TIMBER FASTENINGS

NAILS

WITHDRAWAL RESISTANCE

The force required to start the withdrawal of a nail in the direction of its length from a piece of wood is intimately related to the density or specific gravity (Forest Prod. Lab. Tech. note 236)[28] of the piece and to the depth of penetration. Furthermore, the holding power for a given depth of penetration generally varies directly with the diameter of the nail when the nail is not of a size to cause evident splitting.

Seasoned Wood

Tests made at the Forest Products Laboratory indicate that the load required to withdraw common wire nails soon after driving into the side grain of seasoned wood is

$$P = 6900\ G^{2\frac{1}{2}}\ D$$

in which P represents the ultimate load per lineal inch of penetration; G, the specific gravity based on oven-dry weight and volume when oven dry; and D, the diameter of the nail in inches.

If a factor of safety of 6 is applied to this equation, the safe load (P_1) becomes

$$P_1 = 1150\ G^2\ \ D$$

The relationships expressed in these equations are general, and certain species are known to give somewhat higher values whereas others fall below the equation values. The general expressions should therefore be used with reservation. Usually common knowledge of the characteristics of a species with particular reference to its splitting tendencies will aid in deciding whether it will fall above or below the general run of species.

In table 28 are listed several species of widely different characteristics and opposite each are given recommended safe withdrawal loads for sixpenny to sixtypenny common wire nails calculated by the foregoing formula for safe loads except that corrections have been made for the computed values for Sitka spruce, northern white pine, and southern yellow pine in order to bring these three woods into closer agreement with the values obtained from actual tests. For Sitka spruce the values given in the table are 10 percent greater than the calculated values, and for northern white pine they are 20 percent greater. The values for longleaf and shortleaf pine are 80 percent of the equation value for sixpenny and twelvepenny sizes, 70 percent of the equation values for the twentypenny and larger sizes, and the values for sixteenpenny nails approximately intermediate between those for the twelvepenny and twentypenny sizes.

[28] For further information, the references at the end of this section should be consulted.

TABLE 28.—*Safe resistance to withdrawal of common wire nails driven perpendicular to the grain into seasoned wood*

[Values in pounds per linear inch of penetration into the main member receiving the point]

Species	Specific gravity [1]	Size of nail									
		Sixpenny	Eightpenny	Tenpenny	Twelvepenny	Sixteenpenny	Twentypenny	Thirtypenny	Fortypenny	Fiftypenny	Sixtypenny
Birch, yellow and sweet	0.69	51	60	67	67	74	87	94	102	111	120
Douglas fir	.51	24	28	32	32	35	41	44	48	52	56
Maple, sugar	.68	50	57	65	65	71	84	91	99	107	115
Oak, red and white	.69	51	60	67	67	74	87	94	102	111	120
Pine, longleaf	.64	34	39	45	45	47	50	55	59	64	69
Pine, northern white	.37	13	15	17	17	19	22	24	26	28	30
Pine, ponderosa	.42	15	17	19	19	21	25	27	30	32	35
Pine, shortleaf	.59	28	32	36	36	38	41	44	48	52	57
Redwood	.42	15	17	19	19	21	25	27	30	32	35
Spruce, Sitka	.40	14	17	19	19	21	25	27	29	31	34

[1] Based on weight and volume when oven dry.

UNSEASONED WOOD

If nails are driven into green wood and pulled before any drying takes place, the withdrawal resistance for practically all species of wood will run somewhat higher than that for nails driven in seasoned wood and pulled soon after driving. However, if nails are driven into green wood and seasoning takes place before they are pulled, most types of nails lose a large part of their holding power, the loss being greater for some species of wood than for others. Woods like southern yellow pine, black walnut, chestnut, and some of the oaks retain most of their holding power under the conditions described; whereas others, like birch, maple, white fir, the western pines, and some of the oaks lose far more of their holding power than the general run of species. Aside from the fact that the nail-holding values become erratic under this condition of use, it is difficult to predict how an individual species will behave.

Barbed and spirally grooved or screw nails when driven into green wood retain most of their original holding power when the piece dries.

FACTORS THAT AFFECT NAIL-HOLDING POWER

Pertinent factors that affect the withdrawal resistance of nails in addition to moisture changes already described are the kind of surface of the nail, form of point, form of shank, direction of driving, and the use of bored holes.

NAIL COATINGS

A good quality cement coating will increase the resistance of nails to withdrawal immediately after driving 85 to 100 percent as compared with plain nails, or even more for the lighter woods, such as the softer pines, this increase dropping off in the heavier woods, like hard maple, birch, or oak, to practically no advantage over a plain nail. The increase in the softer woods partly disappears in time so that after a month or so only about one-half of the increase remains. A

chemically etched nail developed at the Forest Products Laboratory (Gahagan and Beglinger) has from 180 to 200 percent higher holding power than a plain nail in the softer woods and unlike the cement-coated nail, it has from 90 to 175 percent more holding power than a plain nail in the denser hardwoods.

A zinc coating is given to nails primarily to reduce or prevent their corrosion. If the coating is evenly applied it may increase the resistance to withdrawal but extreme irregularities of the coating may actually reduce the holding power.

Nail Points

In general, a nail with a long sharp point (fig. 15, *A*) will have a higher holding power than one with the common point (fig. 15, *B*) (Markwardt and Gahagan, third reference). This statement is particularly true for the softer woods. However, if a species has a decided tendency to split, this tendency will be accentuated by a sharp point with a possible reduction in holding power. A blunt or flat point with no taper (fig. 15, *C*) will reduce splitting, but the destruction of the fibers in driving reduces the holding power of the blunt nail below that of the common nail. A nail tapered at the end and terminating in a blunt point (fig. 15, *D*) will not split the wood so badly as a common nail, and in the heavier woods it is equal to the common nail in holding; in the less dense woods its resistance to withdrawal is less than that of the common nail. Although blunt-tapered nails are not now on the market, they may have sufficient advantages to warrant manufacture for special uses.

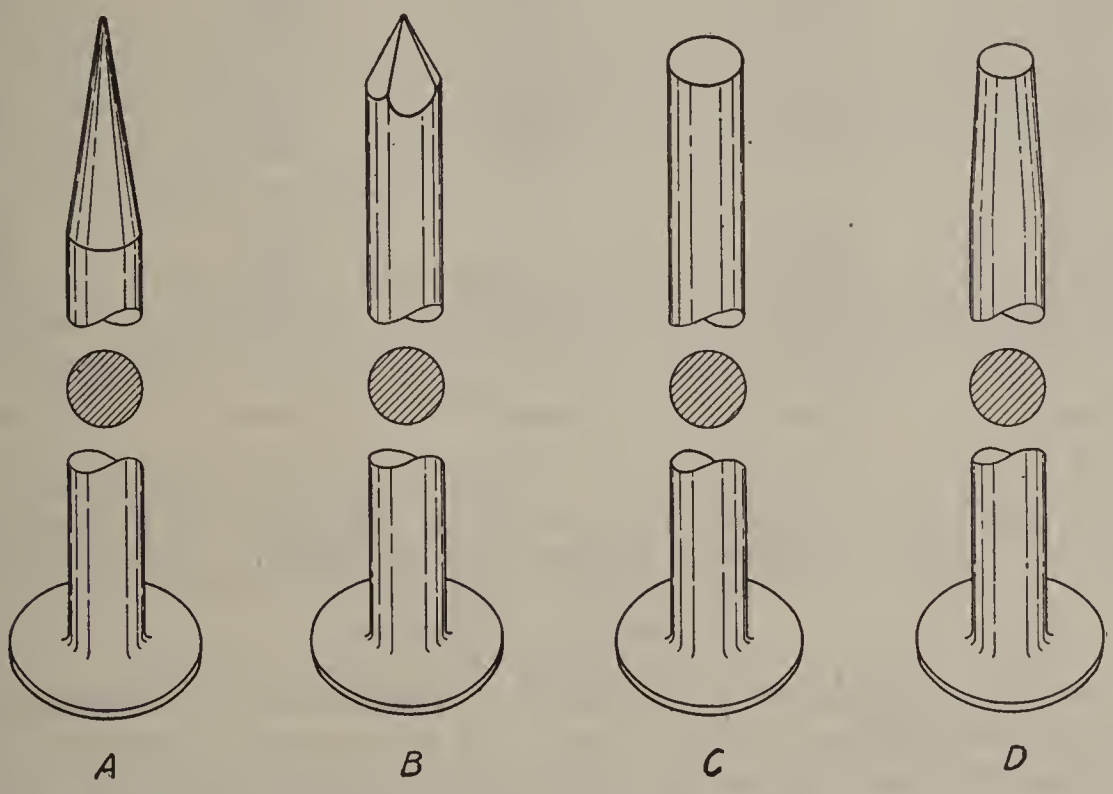


Figure 15.—Types of nail points: *A*, Long and sharp; *B*, common; *C*, blunt; *D*, blunt tapered.

Nail Shanks

In some designs the shanks of nails are varied in form (Markwardt and Gahagan, first reference) to give increased area without an increase in weight. There are barbed, longitudinally grooved, spirally grooved, square, and triangular forms (fig 16), all of which except the barbed nail give higher resistance to withdrawal under

all moisture conditions than does a plain nail. The barbed nail also gives higher resistance to withdrawal than a plain nail when moisture changes occur in the wood before the nail is withdrawn. This is especially true of nails driven into green wood that is then allowed to season; under such conditions a plain nail normally loses most of its holding power whereas a barbed nail retains a large percentage of its original resistance to withdrawal. When a barbed nail is driven into green or dry wood and pulled immediately, its resistance to withdrawal is less than that of a plain nail.

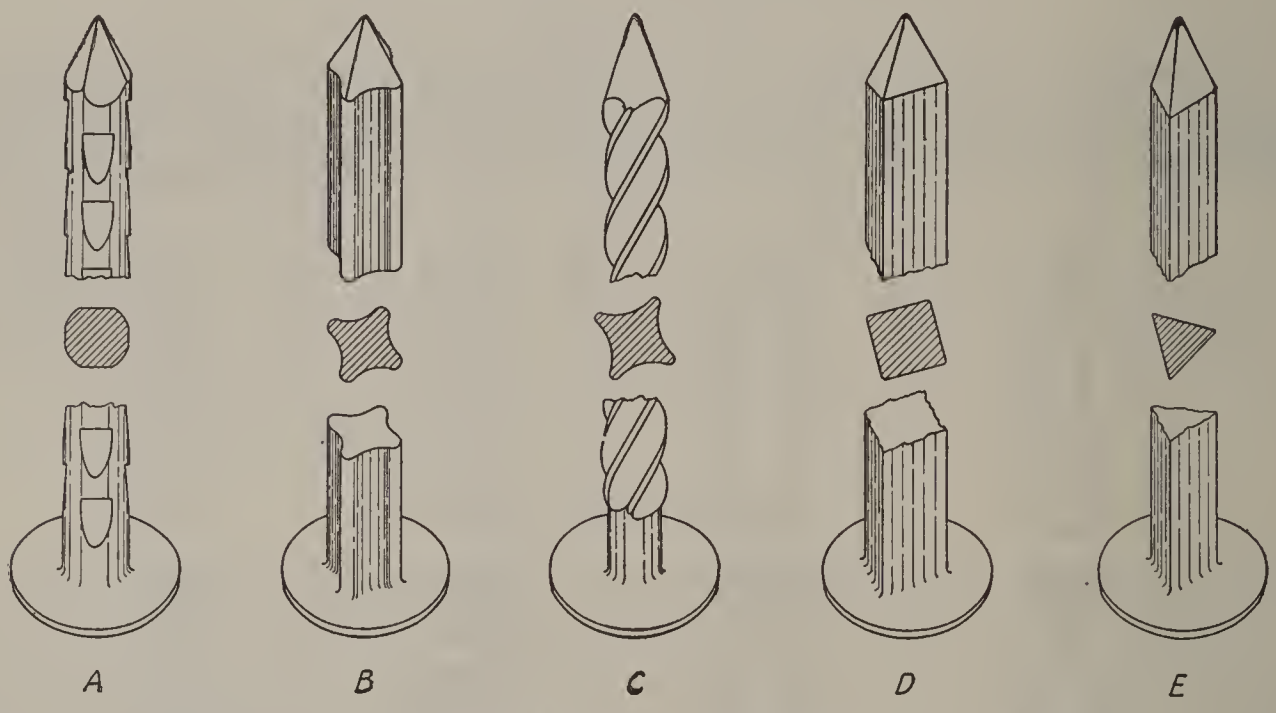


FIGURE 16.—Types of nail shanks: *A*, barbed; *B*, longitudinally grooved; *C*, spirally grooved; *D*, square; *E*, triangular.

DIRECTION OF DRIVING

In general nails have a maximum resistance to withdrawal when driven perpendicular to the grain of the wood. As the angle becomes less, the resistance in the softer woods decreases until when driven parallel to the grain, that is, into the end of a piece, the holding power drops to 75 or even 50 percent of that obtained when the nail is driven perpendicular to the grain. In the very dense hardwoods the resistance to withdrawal is affected little by the angle at which the nail is driven.

The results of tests at the Forest Products Laboratory on slant driving compared with straight driving (Markwardt and Gahagan, second reference) when the piece attached is pulled directly away from the other show that: (1) when driven into green material and pulled immediately straight driving is superior; (2) when driven into dry material and pulled immediately slant driving is usually superior; (3) when driven into green or partially dry material and allowed to season for a month or more slant driving is decidely superior.

Cross slant driving of groups of nails is usually somewhat better than parallel slant driving.

PREBORED HOLES

Nails driven into bored holes slightly less in diameter than that of the nail have a somewhat higher holding power than nails without lead holes. This procedure also prevents or reduces splitting.

LATERAL RESISTANCE

Seasoned Wood

The Forest Products Laboratory recommends the following equation for expressing the safe lateral load for wire nails:

$$P = KD^{3/2}$$

in which P, represents the lateral load in pounds per nail; K, a constant; and D, diameter of nail in inches. The actual equations recommended for various groups of species are given in the following tabulation. In general, these equations were obtained by dividing the constants in the general equation for proportional-limit loads by an arbitrary factor of 1.6. They apply to wood at about 15 percent moisture content. Maximum loads with coniferous woods will be about 6 times and with hardwoods about 11 times the recommended safe loads. It is apparent that for hardwoods the maximum loads are much farther beyond the proportional-limit loads than for coniferous woods.

Equation for computing safe lateral resistance for common wire nails driven perpendicular to the grain of wood at 15-percent moisture content expressed in pounds per nail

Species of wood	Equation
Softwoods:	
Cedar, northern and southern white	$P = 900D^{3/2}$
Fir, balsam and commercial white	
Hemlock, eastern	
Pine, lodgepole, ponderosa, sugar, northern white, and western white	
Spruce, Engelmann, red, Sitka, and white	
Cedar, Alaska, incense, Port Orford, and western red	$P = 1125D^{3/2}$
Cedar, eastern red	
Cypress, southern	
Douglas fir (Rocky Mountain region)	
Hemlock, western	
Pine, Norway	
Redwood	
Tamarack	
Douglas fir (coast region)	$P = 1375D^{3/2}$
Larch, western	
Pine, southern yellow	
Hardwoods:	
Aspen and largetooth aspen	$P = 900D^{3/2}$
Basswood	
Butternut	
Chestnut	
Cottonwood, black and eastern	
Poplar, yellow	
Alder, red	$P = 1250D^{3/2}$
Ash, black	
Birch, paper	
Elm, American and slippery	
Gum, black, red, and tupelo	
Hackberry	
Magnolia, cucumber	
Magnolia, evergreen	
Maple, bigleaf	
Maple (soft), red and silver	
Sugarberry	
Sycamore	

Equation for computing safe lateral resistance for common wire nails driven perpendicular to the grain of wood at 15-percent moisture content expressed in pounds per nail—Continued

Species of wood	Equation
Hardwoods—Continued	
Ash, commercial white	$P=1700D^{3/2}$
Ash, Oregon	
Beech	
Birch, sweet and yellow	
Cherry, black	
Elm, rock	
Hickory, true and pecan	
Honey locust	
Locust, black	
Maple (hard), black and sugar	
Oak, commercial red and white	
Walnut, black	

Values for converting size of nails from penny to $D^{3/2}$, applicable only to common wire nails, are as follows:

Size of nail:	$D^{3/2}$
Fourpenny	0.0311
Sixpenny	.0380
Eightpenny	.0474
Tenpenny	.0570
Twelvepenny	.0570
Sixteenpenny	.0652
Twentypenny	.0841
Thirtypenny	.0942
Fortypenny	.1068
Fiftypenny	.1205
Sixtypenny	.1349

The recommendations are based on a depth of penetration into the block receiving the point of from not less than one-half the length of the nail for dense hardwoods to two-thirds the length of the nail for the softer woods. The recommendations also assume that the cleats are not greatly different in density than the block holding the point. If the nails are holding metal to wood the safe lateral resistance as determined from equations given in the tabulation can be increased about 25 percent.

If the character of the work is such that it appears safe to use higher loads, or if in the opinion of the designer it is felt that the factors of safety used are generally too conservative, the coefficient preceding $D^{3/2}$ may be raised accordingly. The Laboratory, however, does not recommend smaller factors of safety for permanent concealed joints.

LATERAL RESISTANCE OF NAILS AS AFFECTED BY DIRECTION OF DRIVING

The equations given in the tabulation on page 123 apply to wire nails driven at right angles to the grain, and it makes practically no difference whether the load is applied in a direction parallel to the grain of the pieces joined or at right angles to it. When nails are driven parallel to the grain, that is, into the end grain, limited data on softwood species indicate that their maximum resistance to lateral displacement is about two-thirds of that for nails driven perpendicular to the grain. While the average proportional-limit

loads appear to be about the same for parallel and perpendicular driving, the individual results are more erratic for parallel driving and the minimums approach only 75 percent of corresponding values for perpendicular driving. Therefore, the Laboratory recommends that the safe lateral loads for nails driven parallel to the grain, that is, into the end of a piece, should be about 60 percent of those for nails driven perpendicular to the grain. It is quite likely that a higher percentage than 60 could safely be used for the denser hardwood species.

Unseasoned Wood

From the data available it appears that the lateral resistance of nails driven into green wood and loaded while the timber is still green is less than the resistance in seasoned wood. This statement applies almost entirely to proportional-limit loads which, of course, are of prime importance in establishing working loads. The reduction in maximum load is slight, if any. It is recommended that the safe lateral loads given for nails in seasoned wood be reduced 25 percent when applied to nails driven into unseasoned wood which will remain wet or will be loaded before seasoning has taken place.

When nails are driven into green wood their lateral proportional-limit loads after the wood has seasoned is also less than when driven into seasoned wood and then loaded. The meager information and erratic behavior make it difficult to recommend safe lateral loads for nails driven into green wood and loaded during and subsequent to seasoning. Important structural joints subject to these conditions should be inspected at intervals; and if it becomes apparent that the joints have lost strength as the timbers dried, they should be reenforced with additional nails. Simply setting the old nails is not sufficient.

SPIKES

COMMON WIRE SPIKES

Common wire spikes are manufactured in the same manner as common wire nails. They have either a chisel point or a diamond point and are made in lengths of from 3 to 12 inches. For corresponding lengths they have larger diameters than common wire nails and beyond the sixtypenny size they are usually designated by inches of length. The safe withdrawal resistance in pounds per lineal inch when driven perpendicular to the grain may be calculated by the formula

$$P = 1150\ G^{2\frac{1}{2}}\ D$$

subject to the limitations given in the discussion of common wire nails (p. 119). In the formula P is the safe withdrawal load in pounds per inch of penetration; G is the specific gravity of the wood; and D is the diameter of the spike in inches. In calculating the withdrawal load two-thirds of the length of the point should be neglected.

To illustrate the method of calculation and the application of the limitations set up under the discussion of common nails, let it be required to calculate the safe withdrawal resistance per lineal inch of a common wire spike one-half inch in diameter driven in longleaf pine. The specific gravity from table 28 is 0.64, and the equation

values for longleaf pine must be multiplied by 0.70 for diameters greater than that of a sixteenpenny common wire nail. Hence

$$P=0.7\times1150\times0.64\ ^{2\frac{1}{2}}\times0.5=132 \text{ pounds}$$

For oak the safe withdrawal load per lineal inch would be

$$P=1150\times0.69\ ^{2\frac{1}{2}}\times0.5=227 \text{ pounds}$$

The foregoing recommendations assume that the spikes are driven into pieces of sufficient width and length and sufficiently far from the ends or edges to avoid unusual splitting. As indicated in the discussion of common wire nails, the safe loads are based on a factor of about six as regards the maximum withdrawal resistance from seasoned wood.

The lateral resistance of common wire spikes may be calculated by the formulas given on page 123 for common wire nails.

BOAT SPIKES

Boat spikes are square in cross section and are made in thicknesses of ¼, 5/16, ⅜, 7/16, ½, and ⅝ inch. They have a chisel- or wedge-shaped point and are made in lengths of about 3 to 8 inches for the smallest and about 6 to 14 inches for the largest thicknesses.

Tests on the holding power of three sizes of boat spikes driven in white pine are reported by Jacoby and Davis (table 29).

TABLE 29.—*Ultimate holding power in white pine of boat spikes per lineal inch* [1]

Size of spike (inch)	Holding power per lineal inch	Direction of edge of point relative to grain	Size of spike (inch)	Holding power per lineal inch	Direction of edge of point relative to grain
	Pounds			*Pounds*	
⅜	370	Across.	7/16	436	Parallel.
⅜	450	Parallel.	½	429	Across.
7/16	344	Across.	½	521	Parallel.

[1] Data from Jacoby and Davis.

DRIFT BOLTS

As with common wire nails and spikes, the resistance to withdrawal of round drift bolts inserted perpendicular to the grain is intimately related to the density or specific gravity of the wood and tests at the Laboratory indicate that this relation may be expressed as follows:

$$P=6000\ G^2\ D$$

in which P, represents the maximum withdrawal load per lineal inch of penetration; G, the specific gravity based on the weight and volume of the oven-dry wood; and D, the diameter of the drift bolt in inches.

The above expression presumes that the bolts are driven into holes having a diameter of one-eighth inch less than that of the bolt diameter.

The influence of specific gravity accounts in large measure for the differences in test results recorded by various investigators. Further, as explained in connection with the withdrawal resistance of nails, test results for certain species will follow the above general relationship quite well, others will yield results above the equation values, and still others will give values below the equation values.

Species that would be expected to follow equation values closely are ponderosa pine, Douglas fir, redwood, and the hardwoods, such as oak. Test results for southern yellow pine were about 80 percent of those indicated by the general formula. No safe working loads are suggested. The character of the work must indicate to the engineer what factor of safety should be applied to the ultimate values just discussed.

WOOD SCREWS

LATERAL RESISTANCE

The safe lateral loads for wood screws (Dewell and Kolberk and Birnbaum) of various gages and for various groups of species are given in the following tabulation, in the form of equations, in which P is the safe lateral load, and D is the diameter of the shank. Loads resulting from the use of these equations would be expected to give a slip somewhere between 0.007 and 0.01 of an inch, and would vary somewhat with species and quality of wood. In general, these equations were obtained by dividing the constants in the general equations for proportional-limit loads

$$P = K\ D^2$$

by an arbitrary factor of 1.6.

Equations for computing the safe lateral loads for wood screws in wood at 15 percent moisture content expressed in pounds per screw

Species of wood	Equation
Softwoods:	
Cedar, northern and southern white	$P=2100\ D^2$.
Fir, balsam and commercial white	
Hemlock, eastern	
Pine, lodgepole, ponderosa, sugar, northern white, and western white	
Spruce, Engelmann, red, Sitka, and white	
Cedar, Alaska, incense, Port Orford, and western red	$P=2700\ D^2$.
Cedar, eastern red	
Cypress, southern	
Douglas fir (Rocky Mountain region)	
Hemlock, western	
Pine, Norway	
Redwood	
Tamarack	
Douglas fir (coast region)	$P=3300\ D^2$.
Larch, western	
Pine, southern yellow	
Hardwoods:	
Aspen and largetooth aspen	$P=2100\ D^2$.
Basswood	
Butternut	
Chestnut	
Cottonwood, black and eastern	
Poplar, yellow	

Equations for computing the safe lateral loads for wood screws in wood at 15 percent moisture content expressed in pounds per screw—Continued

Species of wood	Equation
Hardwoods—Continued	
Alder, red	$P=2900\ D^2$.
Ash, black	
Birch, paper	
Elm, American and slippery	
Gum, black, red, and tupelo	
Hackberry	
Magnolia, cucumber	
Magnolia, evergreen	
Maple, bigleaf	
Maple (soft), red and silver	
Sugarberry	
Sycamore	
Ash, commercial white	$P=4000\ D^2$.
Ash, Oregon	
Beech	
Birch, sweet and yellow	
Cherry, black	
Elm, rock	
Hickory, true and pecan	
Honey locust	
Locust, black	
Maple (hard), black and sugar	
Oak, commercial red and white	
Walnut, black	

Values for converting screw gage into D^2 are as follows:

Number or gage:	D^2	Number or gage—Continued.	D^2
0	0.0036	9	0.0313
1	.0053	10	.0361
2	.0074	11	.0412
3	.0098	12	.0467
4	.0125	14	.0586
5	.0156	16	.0718
6	.0190	18	.0864
7	.0228	20	.1024
8	.0269	24	.1384

The equations apply to wood at about 15-percent moisture content. They are based on data from screws in which the depth of penetration into the block receiving the point was not less than 7 times the screw diameter.

With the length of screw in the holding block equal to 7 times the shank diameter, the maximum load will be approximately 6 times the recommended safe loads. If the depth of penetration is less than 7 times the diameter of the shank, the proportional limit and the maximum loads will both be reduced, the maximum load dropping about in proportion to the reduction in length and the proportional limit somewhat less rapidly. When the depth of penetration of the screw in the holding block is 4 times the shank diameter the maximum load will be less than 4 times the loads given in the table and the proportional limit loads will be approximately equal to those given. The equations assume that the cleats are not greatly different in density than the block holding the point. If the screws are holding metal to wood, the safe lateral resistance as determined from these equations can be increased about 25 percent.

For hardwoods, such as oak, the part of the lead hole receiving the shank was of the same diameter as the shank, and that receiving the threaded portion was the same as the diameter at the root of the thread. For conifers, such as southern pine and Douglas fir, the part of the hole for the shank was about seven-eighths the diameter of the shank and that for the threaded portion about seven-eighths the diameter of the screw at the root of the thread.

If the character of the work is such that it appears safe to use higher loads and greater slips, other factors can be readily applied by changing the coefficient preceding D^2 in the various equations.

WITHDRAWAL RESISTANCE

The resistance to withdrawal of common wood screws inserted into the side grain of seasoned wood is intimately related to the density or specific gravity of the piece and, within certain limits, varies directly with the depth of penetration and the diameter of the screw. Tests made by the Bureau of Standards indicate that this relation may be expressed as follows:

$$P = 10{,}200\ G^2\ D$$

in which P is the ultimate load per inch of total length, G is the specific gravity based on oven-dry weight and volume when tested, and D is the diameter of the screw in inches. If a factor of 6 is applied to this equation the safe load (P_1) becomes

$$P_1 = 1{,}700\ G^2\ D$$

In the foregoing equation it is presumed that the depth of penetration into the block receiving the point is not less than two-thirds the length of the screw, and that in softwoods the screws are inserted into holes with a diameter of about 70 percent of the root diameter of the screw and in hardwoods about 90 percent.

The equation may be used for all species, but inherent characteristics may cause some species to give values 10 to 15 percent above or below the equation values, while an occasional species may vary more than this.

The equation values are applicable to the following screw lengths and gages:

Screw length:	*Gage limits*	Screw length—Continued.	*Gage limits*
½	1–6	2	7–16
¾	2–11	2½	9–18
1	3–12	3	12–20
1½	5–14		

For lengths and gages outside of these limits the actual values are likely to be less than the equation values, especially in the denser woods where screw failures often occur.

When screws are driven parallel to the grain, that is, into the end grain of a piece, the individual results are erratic, but where splitting can be avoided they should be, on the average, about 75 percent of the load computed for side grain.

Lubricating the surface of a screw to facilitate driving in dense woods will have little effect on its ultimate withdrawal resistance.

BOLTS

BEARING STRENGTH OF WOOD UNDER BOLTS

The slip in a bolted timber joint is proportional to the load up to a certain point, which may be regarded as a proportional limit even though in the true sense of the word it is not one, since the joint will have a slight set if the load is removed. The stress in the wood under the bolt is not uniform; on the contrary it is concentrated at the edges of the timbers somewhat as shown by shaded areas in figure 17. The properties of the wood and of the bolt both play a part in producing the proportional limit.

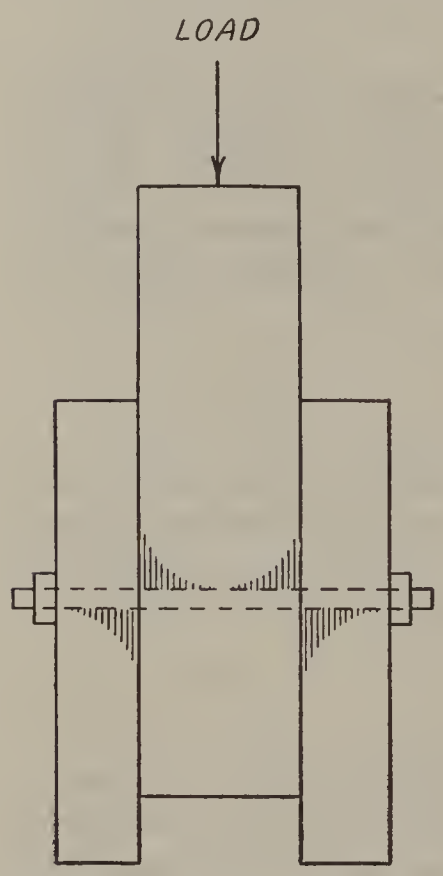


FIGURE 17.—The stress in wood under the bolt is concentrated at the edges of the timbers as shown by the shaded areas.

The Forest Products Laboratory through hundreds of tests (Trayer) has established the fact that at some load the slip ceases to be proportional to the load, that the slip at this load is small, usually only a few hundredths of an inch, and that the load at this point can be sustained repeatedly without any increase in slip or other evident injury.

Safe loads, based on proportional-limit loads, may be calculated from the data in tables 30, 31, and 32. For convenience, in the procedure given, all bearing stresses are considered uniformly distributed over the projected area of the bolt. If the ratio of the length of bolt in a timber to its diameter (L/D) is small, the bearing stress will be substantially uniform; the basic stresses given in table 30 apply to such a condition. For larger L/D ratios the assumed uniform stress is reduced in accordance with the ratios given in tables 31 and 32.

In setting up basic stresses the compressive properties of green wood were adjusted for long-time loading, for an inherent difference in the reaction of hardwoods and conifers to bolt-bearing stresses, and for an increase in strength with seasoning. To the adjusted values a factor was applied to cover variability and factor of safety.

When the following rules for calculating the safe loads for bolted timber joints are followed, the safe uniform stress will drop off for increasing L/D ratios in the same fashion that the average proportional-limit stress was found to drop off in test. In effect, this means that safe stresses for the longer bolts are based on proportional-limit stresses.

LOADS ACTING PARALLEL WITH THE GRAIN

To calculate the safe working value of a load on a timber joint that is applied parallel with the grain through metal plates at both ends of the bolts (fig. 18, A, a), proceed as follows:

(1) Select from table 30 the basic stress in compression parallel with the grain for the kind of wood used and for the service condition that applies. Call this stress S_1.

TABLE 30.—*Basic stresses for calculating safe loads for bolted joints*

[These stresses, when used in conjunction with tables 31 and 32, give safe bolt-bearing stresses. They apply to seasoned timbers used in a dry, inside location. For other conditions, reduce each stress as follows: When the timbers are occasionally wet but quickly dried, use three-fourths of the stress listed; if damp or wet most of the time, use two-thirds]

Group	Species of wood	Basic stress	
		Parallel with the grain	Perpendicular to the grain
	Softwoods (conifers):		
1	Cedar, northern and southern; fir, balsam and commercial white; hemlock, eastern; pine, lodgepole, ponderosa, sugar, northern white, and western white; spruce, Engelmann, red, Sitka, and white	*Lb. per sq. in.* 800	*Lb. per sq. in.* 150
2	Cedar, Alaska, incense, Port Orford, and western red; Douglas fir (Rocky Mountain region); hemlock, western; pine, Norway	1,000	200
3	Cedar, eastern red; cypress, southern; Douglas fir (coast region); larch, western; pine, southern yellow; redwood; tamarack	1,300	275
	Hardwoods (broad-leaved species):		
1	Ash, black; aspen and largetooth aspen; basswood; birch, paper; butternut; chestnut; cottonwood, black and eastern; poplar, yellow	925	175
2	Alder, red; elm, American and slippery; gum, black, red, and tupelo; hackberry; magnolia, cucumber and evergreen; maple, bigleaf, and red and silver (soft); sugarberry; sycamore	1,200	250
3	Ash, commercial white and Oregon; beech; birch, sweet and yellow; cherry, black; elm, rock; hickory, true and pecan; honey locust; locust, black; maple (hard), black and sugar; oak, commercial red and white; walnut, black	1,500	400

TABLE 31.—*Percentage of basic stress parallel with the grain for calculating safe bearing stresses under bolts*

[The product of the basic stress parallel with the grain selected from table 30 and the percentage for the particular L/D ratio and species group, taken from this table, is the safe working stress at that ratio for joints with metal splice plates. When wood splice plates are used, each one-half the thickness of the main timber, 80 percent of this product is the safe working stress]

Length of bolt in main member divided by its diameter (L/D)	Percentage of basic stress for—					
	Common bolts [1]			High-strength bolts [2]		
	Group 1 woods	Group 2 woods	Group 3 woods	Group 1 woods	Group 2 woods	Group 3 woods
1	100.0	100.0	100.0	100.0	100.0	100.0
1.5	100.0	100.0	100.0	100.0	100.0	100.0
2	100.0	100.0	100.0	100.0	100.0	100.0
2.5	100.0	100.0	99.7	100.0	100.0	100.0
3	100.0	100.0	99.0	100.0	100.0	100.0
3.5	100.0	99.3	96.7	100.0	100.0	99.7
4	99.5	97.4	92.5	100.0	100.0	99.0
4.5	97.9	93.8	86.8	100.0	100.0	97.8
5	95.4	88.3	80.0	100.0	99.8	96.0
5.5	91.4	82.2	73.0	100.0	98.2	93.0
6	85.6	75.8	67.2	100.0	95.4	89.5
6.5	79.0	70.0	62.0	98.5	92.2	85.2
7	73.4	65.0	57.6	95.8	88.8	81.0
7.5	68.5	60.6	53.7	92.7	85.0	76.8
8	64.2	56.9	50.4	89.3	81.2	73.0
8.5	60.4	53.5	47.4	85.9	77.7	69.6
9	57.1	50.6	44.8	82.5	74.2	66.4
9.5	54.1	47.9	42.4	79.0	71.0	63.2
10	51.4	45.5	40.3	75.8	68.0	60.2
10.5	48.9	43.3	38.4	72.5	64.8	57.4
11	46.7	41.4	36.6	69.7	61.9	54.8
11.5	44.7	39.6	35.0	66.8	59.2	52.4
12	42.8	37.9	33.6	64.0	56.7	50.2
12.5	41.1	36.4	32.2	61.4	54.4	48.2
13	39.5	35.0	31.0	59.1	52.4	46.3

[1] Bolts having a yield point of approximately 45,000 pounds per square inch.
[2] Bolts having a yield point of approximately 125,000 pounds per square inch.

TABLE 32.—*Percentages of basic stress perpendicular to the grain used in calculating safe bearing stresses under bolts*

[The safe working stress for a given value of L/D is the product of 3 factors: (1) the basic stress perpendicular to the grain taken from table 30, (2) the percentage from this table, and (3) the factor for bolt diameter, also from this table [1]]

Length of bolt in main member divided by its diameter (L/D)	Percentage for common bolts [2]				Percentage for high-strength bolts [3]
	Group 1 conifers and group 1 hardwoods	Group 2 conifers	Group 2 hardwoods and group 3 conifers	Group 3 hardwoods	All groups
1 to 5, inclusive	100.0	100.0	100.0	100.0	100.0
5.5	100.0	100.0	100.0	99.0	100.0
6	100.0	100.0	100.0	96.3	100.0
6.5	100.0	100.0	99.5	92.3	100.0
7	100.0	100.0	97.3	86.9	100.0
7.5	100.0	99.1	93.3	81.2	100.0
8	100.0	96.1	88.1	75.0	100.0
8.5	98.1	91.7	82.1	69.9	99.8
9	94.6	86.3	76.7	64.6	97.7
9.5	90.0	80.9	71.9	60.0	94.2
10	85.0	76.2	67.2	55.4	90.0
10.5	80.1	71.6	62.9	51.6	85.7
11	76.1	67.6	59.3	48.4	81.5
11.5	72.1	64.1	55.6	45.4	77.4
12	68.6	61.0	52.0	42.5	73.6
12.5	65.3	58.0	49.0	40.0	70.2
13	62.2	55.3	45.9	37.5	66.9

Diameter of bolt, inches	¼	⅜	½	⅝	¾	⅞	1	1¼	1½	1¾	2	2½	3 and over.
Diameter factor	2.50	1.95	1.68	1.52	1.41	1.33	1.27	1.19	1.14	1.10	1.07	1.03	1

[1] No reduction need be made when wood splice plates are used except that the safe load perpendicular to the grain should never exceed the safe load parallel with the grain for any given size and quality of bolt and timber.

[2] Bolts having a yield point of approximately 45,000 pounds per square inch.

[3] Bolts having a yield point of approximately 125,000 pounds per square inch.

(2) Calculate the ratio of the length of bolt in the main member to its diameter (hereafter this ratio is called L/D) and for this ratio select the proper stress percentage from table 31 for the quality of bolt used. Call this percentage r.

(3) Multiply the basic stress S_1 by the percentage r and the result, S_2, is the safe working stress, which is assumed to be uniformly distributed.

(4) Multiply S_2 by the projected area of the bolt and the result, P_1, is the safe working load for one bolt when the load is applied through metal splice plates.

(5) If the load is applied through wood splice plates, each of which is half the thickness of the center timber, as in figure 18, A, b, the safe load is obtained by multiplying P_1 by 0.80.

(6) When the bolt holes are properly centered, the safe load on a number of bolts, whether of the same diameter or not, may be taken as the sum of their individual load capacities.

EXAMPLES

(1) Calculate the safe working strength of a tension joint like figure 18 A, a, in which two pieces of seasoned coast-region Douglas fir 4 inches thick are joined end to end by means of metal splice

plates and 8 connecting 5/8-inch common bolts; that is, 4 bolts on each side of the butt joint. The service condition may be classed as dry, inside location.

The basic stress from table 30 is 1,300 pounds per square inch. The L/D ratio is $4 \div 0.625 = 6.4$; for this ratio table 31 gives a stress percentage for common bolts of 63. Therefore, the

Safe stress $S_2 = 1{,}300 \times 0.63 = 819$ pounds per square inch.
Safe load P_1 for one bolt $= 819 \times 4 \times 0.625 = 2{,}048$ pounds.
Safe load for four bolts $= 4 \times 2{,}048 = 8{,}192$ pounds.

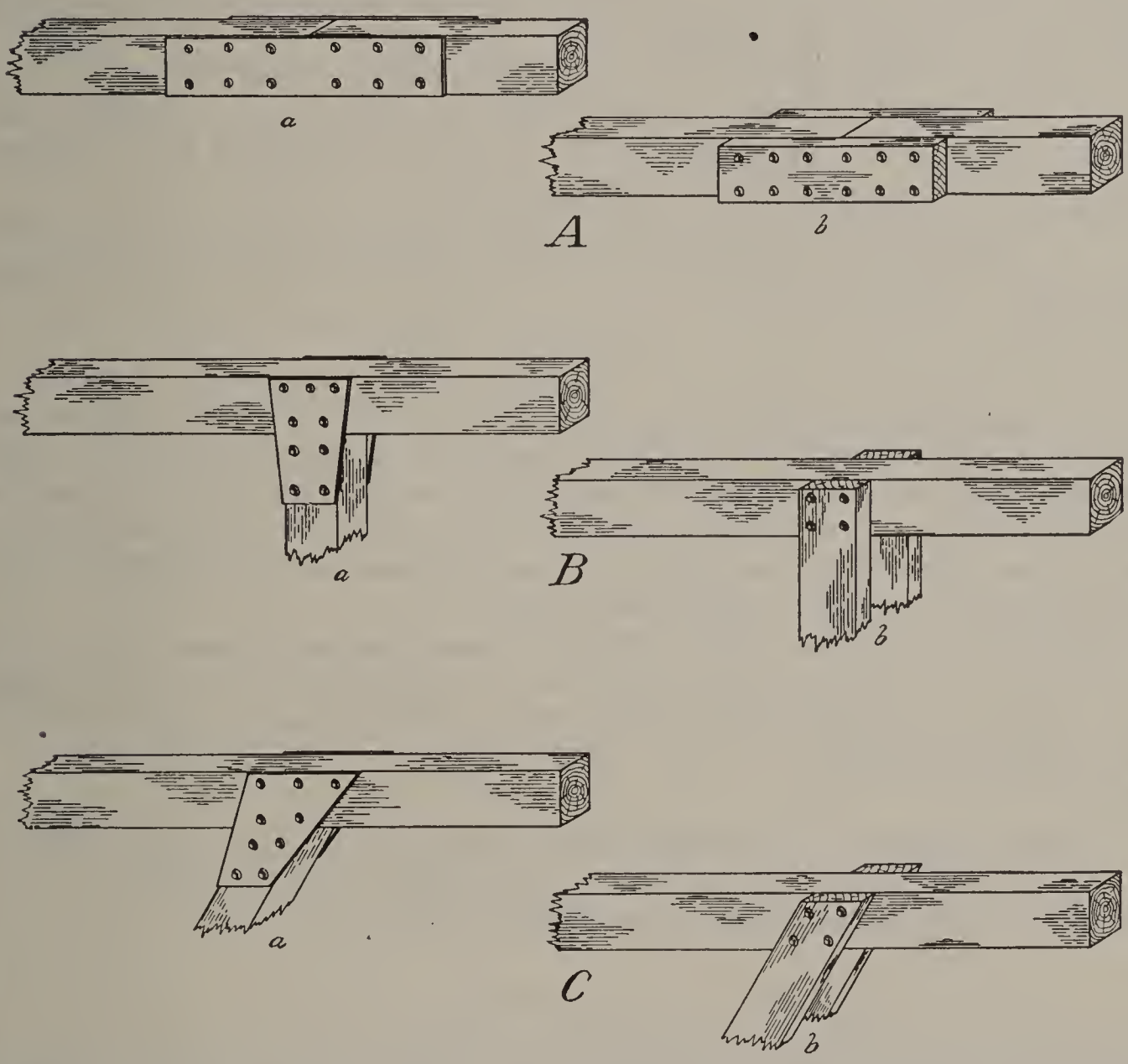


FIGURE 18.—Typical joints with bolts: *A*, Bearing parallel to the grain; *B*, bearing perpendicular to the grain; *C*, bearing at any angle with the grain; *a*, metal splice plates; *b*, wood splice plates or divided member.

(2) Calculate the safe working strength of the joint in example 1 when the splice plates are of 2-inch Douglas fir instead of metal. as figure 18, *A*, *b*. As before:

$P_1 = 1{,}300 \times 0.63 \times 4 \times 0.625 = 2{,}048$ pounds.
Safe load for one bolt $= 0.80 \times 2{,}048 = 1{,}638$ pounds.
Safe load for four bolts $= 4 \times 1{,}638 = 6{,}552$ pounds.

LOADS ACTING PERPENDICULAR TO THE GRAIN

Within certain limits the proportional-limit bearing stress under a small pin or bolt acting perpendicular to the grain will be higher than that for a larger pin or bolt. A list of corrective factors to

take care of this situation appear in the lower portion of table 32. They are referred to as diameter factors in the third calculation step given below.

To calculate the safe working value of a load on a timber joint that is applied perpendicular to the grain through splice plates at both ends of the bolts (fig. 18, *B*, *a* and *b*), proceed as follows:

(1) Select from table 30 the basic stress in compression perpendicular to the grain for the kind of wood used and for the service condition that applies. Call this stress S_1.

(2) Calculate the L/D ratio for the part of the bolt in the main member and for this ratio select the proper stress percentage from table 32. Call this percentage r.

(3) Select the diameter factor from table 32. Call this factor v.

(4) Multiply the basic stress S_1 by the percentage r and by the diameter factor v. The result, $S_1 \times r \times v = S_2$, is the safe unit working stress for the particular L/D ratio used.

(5) Multiply this stress by the projected area of the bolt and the result is the safe working load, whether metal or wood splice plates are used.

EXAMPLE

(1) Calculate the safe load on a joint made by bolting two side timbers at right angles to a center timber, as in figure 18, *B*, *b*. The wood is seasoned coast-region Douglas fir and the condition of service dry, inside location. The center member is 4 inches thick and the side timbers each 2 inches thick. Four common bolts five-eighths inch in diameter are used to make the joint.

The basic stress from table 30 is 275 pounds per square inch. The L/D ratio is $4 \div 0.625$, or 6.4; and the corresponding stress percentage for common bolts from table 32 is 99.6. The diameter of bolt factor from table 32 is 1.52.

Then

Safe stress $S_2 = 275 \times 0.996 \times 1.52 = 416$ pounds per square inch.
Safe load P_1 for one bolt $= 416 \times 4 \times 0.625 = 1{,}040$ pounds.
Safe load for four bolts $= 4 \times 1{,}040 = 4{,}160$ pounds.

Load Acting at an Angle with the Grain

The formula recommended for calculating the bearing stress at any angle with the grain, which may be used for joints like those in figure 18, *C*, is given under the heading Compressive Strength on Surfaces Inclined to the Grain, on page 56.

EFFECT OF QUALITY OF BOLT ON JOINT STRENGTH

Both the quality of the wood and of the bolt help to determine the proportional-limit strength of a bolted joint (Trayer). For this reason, two main groups of percentages appear in tables 31 and 32, one for common bolts and one for high-strength bolts. The approximate yield point for the common is 45,000 and for the high-strength 125,000 pounds per square inch. Ratios for qualities between these two limits may be obtained by interpolation.

A load applied to only one end of a bolt, perpendicular to its axis, may be one-half the symmetrical two-end load. If the one-end load acts at an angle with the axis of the bolt, the component at 90° with the axis may be one-half the two-end load.

The center-to-center distance along the grain between bolts acting parallel with the grain should be at least four times the bolt diameter.

The distance across the grain between rows of bolts acting parallel with the grain is controlled by the reduction in area at the critical section. The net tension area remaining at the critical section, when coniferous woods are used, should be at least 80 percent of the total area in bearing under all the bolts. When hardwoods are used, the net tension area at the critical section should at least equal the bearing area under all the bolts.

If an odd number of bolts of a selected diameter are required in each half of a joint in which an even number of parallel rows are employed, desirable practice will alter the diameter of all or part of the bolts in such a way as to obtain an even number. This will avoid staggering. If staggering is resorted to, however, special precautions must be taken in determining the tension area required at the critical section. The procedure can best be explained by referring to figure 18, *A*, *a*. If a seventh bolt were required in each half of the joint, the usual practice would be to place it in the center of the timber at a longitudinal distance from the present end bolts equal to the longitudinal spacing between the other bolts. In calculating the required area at the critical section, however, the seventh bolt should be considered as placed between the last pair of bolts. This rule, of course, would be unreasonable if the odd bolt were spaced an abnormally great distance from the last pair.

In a tension joint the distance from the end of the timber to the center of the nearest bolt hole should be at least 7 times the bolt diameter when coniferous woods are used, and at least 5 times the bolt diameter when hardwoods are used. When the joint is under a compressive load, this end margin need only be 4 times the bolt diameter for all woods.

The distance from the edge of a timber to the center of a bolt acting parallel with the grain should be at least one and one-half times the bolt diameter for L/D ratios of about 5 or 6. For ratios greater than 6 this edge margin should be increased slightly, and for ratios less than 5 it may be reduced slightly. In most instances the area requirements at the critical section will be such that an edge margin equal to half the distance between rows will be more than sufficient to meet the preceding requirements.

The minimum center-to-center spacing of bolts in the across-the-grain direction for loads acting perpendicular to the grain through metal splice plates need only be sufficient to permit the tightening of the nuts. When such load is applied through wood side plates, the spacing is that required for the side plates if the design load approaches the bolt-bearing capacity. When the design load is less than the bolt-bearing capacity of the side timbers, the spacing may be reduced below that required to develop their maximum capacity.

For loads acting perpendicular to the grain, the margin between the edge toward which the bolt pressure is acting and the center of the bolt or bolts nearest this edge should be at least four times the bolt diameter. The margin at the opposite edge is relatively unimportant.

MODERN CONNECTORS

Modern connectors consist in general of metal rings or plates and wood disks that, embedded partly in each of adjacent members, as in figure 19, transmit the load from one to the other. Essentially their action is like that of a dowel or key. More than 60 different types and variations of such connectors have been patented in Europe and, in a number of instances, in the United States also.

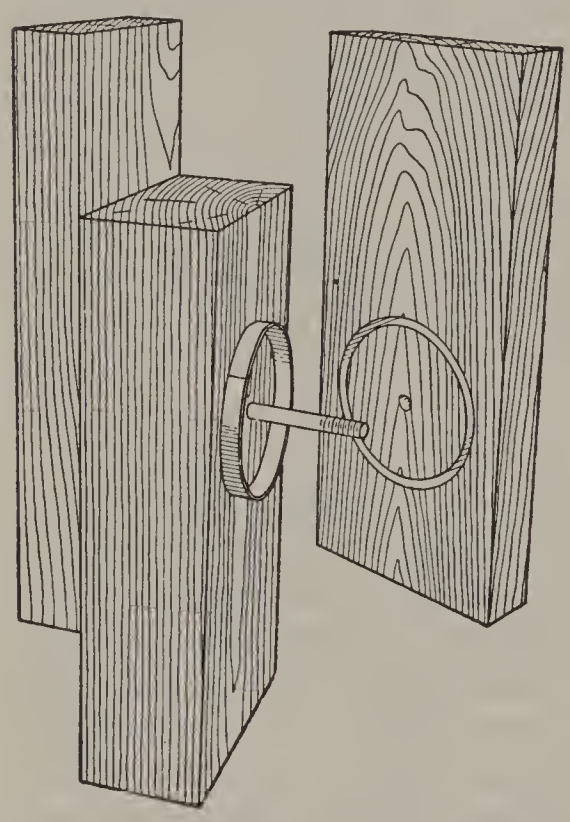


FIGURE 19.—Method of assembling modern connectors.

Several typical connectors have been tested at the Forest Products Laboratory by Perkins, Landsem, and Trayer; two of the most important structural woods, southern yellow pine and Douglas fir, were used in the tests. Figure 20, *A*, shows a test assembly in which connectors placed between each of the side timbers and the center timber bear parallel to the grain of the wood. In figure 20, *B*, the bearing is perpendicular to the grain of the center timber. Other assemblies may involve bearing at any angle between these two. Working loads for each of these conditions based on the tests are given in the following paragraphs.

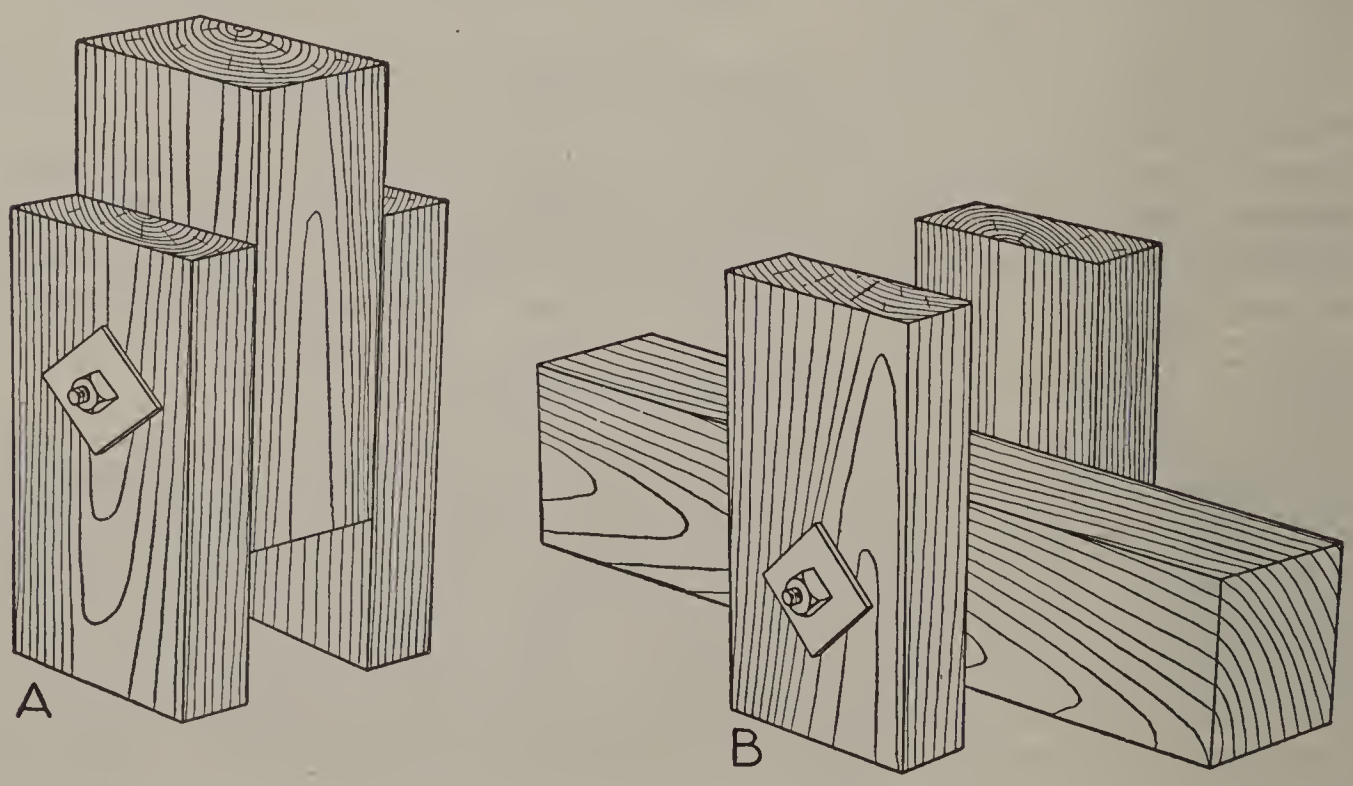


FIGURE 20.—*A*, Assembly in which connectors placed between each of the side timbers and the center timber bear parallel to the grain of the wood; *B*, the bearing is perpendicular to the grain of the center timber.

Working loads for woods other than those tested were obtained by adjusting the test results with due consideration for differences in the mechanical properties of the various species; the loads for some of the connectors varied as the first power of the properties of the wood whereas the loads for others, particularly those with teeth, varied as the square root of the properties of the wood.

ALLIGATOR

The alligator connector (fig. 21) as manufactured in the United States consists of a circular band of 16-gage hot-rolled sheet steel. This type of connector is made in the United States in sizes 2, 2⅝, 3⅜, and 4 inches in diameter with 1-inch teeth. In order to facilitate assembly, the hole for the connecting bolt is bored $\frac{1}{32}$ to $\frac{1}{16}$ inch larger than the diameter of the bolt. The recommended working loads for two alligator connectors symmetically loaded, as in an assembly like figure 20, are given in table 33.

These loads are based on a factor of 4 on ultimate loads of specimens tested at the Forest Products Laboratory. No increase in the loads shown herein is recommended for wind or earthquake load design.

Working loads shown are for toothed rings on seasoned timber; that is, timber which has a moisture content at the time of installation equal to that to which it will eventually come in use. For nearly all parts of the United States this will average about 15 percent for the sur-

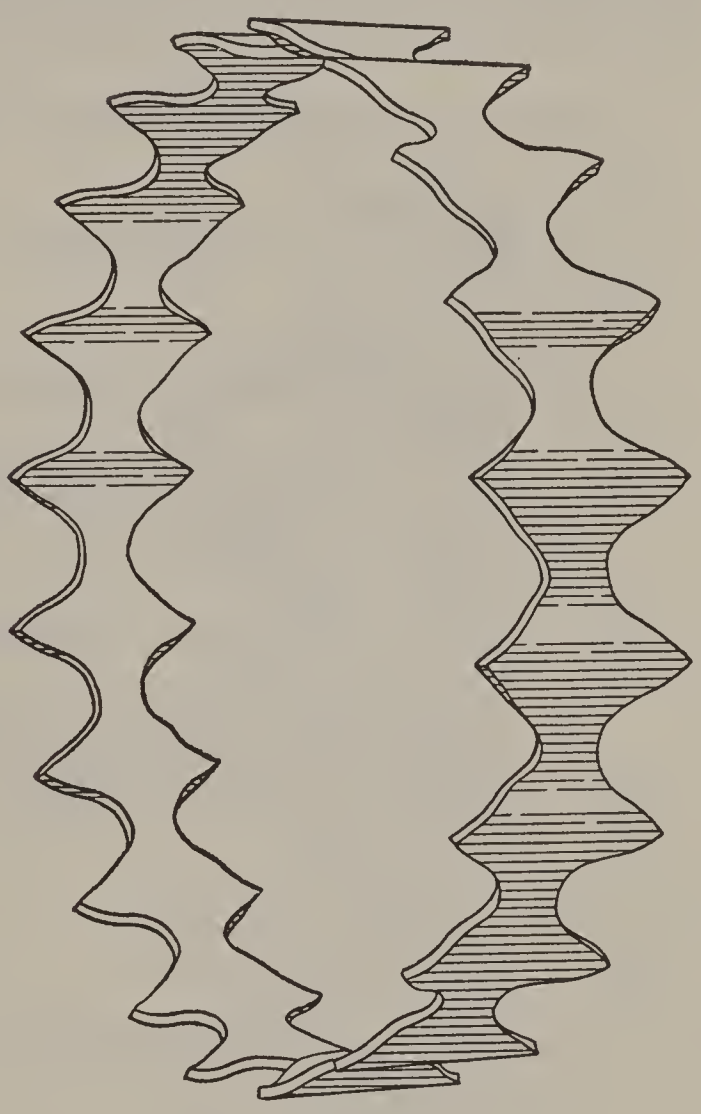


FIGURE 21.—Alligator connector.

TABLE 33.—*Safe loads with seasoned southern yellow pine or Douglas fir (coast region) timbers for 2 symmetrically loaded alligator connectors of sizes manufactured in the United States*

Diameter of connector (inches)	Diameter of bolt	Safe load			
		Parallel with the grain		Perpendicular to the grain	
		Bolt tight in hole	Bolt in oversized hole	Bolt tight in hole	Bolt in oversized hole
	Inch	*Pounds*	*Pounds*	*Pounds*	*Pounds*
2	½	2,400	2,200	1,800	1,650
2⅝	⅝	4,200	3,600	3,150	2,700
3⅜	¾	5,800	5,200	4,350	3,900
4	¾	6,900	6,300	5,200	4,700

faces of the timber. Loads for toothed rings in green (24 percent or more moisture content) timber should not exceed 60 percent of those shown, and for intermediate moisture contents the loads should be interpolated according to the degree of seasoning of the timber surface. For such adjustments assume green timber at 24 percent moisture.

For bearing at angles between 0° and 45° with the grain, the safe loads should be reduced uniformly from those for bearing parallel with the grain to those for bearing perpendicular to the grain. The value for 45° should apply for all angles from 45° to 90°.

The loads for southern yellow pine and Douglas fir may be used safely with all group 4 species listed in the following tabulation. For group 1 species use 80 percent of these values, for group 2 use 85 percent, for group 3 use 90 percent, and for group 5 use 110 percent.

Species of wood grouped according to holding power with modern connectors

Group	Species
1	Ash, black
	Aspen and largetooth aspen
	Basswood
	Birch, paper
	Butternut
	Cedar, northern and southern white
	Chestnut
	Cottonwood, black and eastern
	Fir, balsam and commercial white
	Hemlock, eastern
	Pine, lodgepole, ponderosa, sugar, northern white, and western white
	Poplar, yellow
	Spruce, Engelmann, red, Sitka, and white
2	Alder, red
	Cedar, Alaska, incense, Port Orford, and western red
	Douglas fir (Rocky Mountain region)
	Elm, American and slippery
	Gum, black, red, and tupelo
	Hackberry
	Hemlock, western
	Magnolia, cucumber
	Magnolia, evergreen
	Maple, bigleaf
	Maple (soft), red and silver
	Pine, Norway
	Sugarberry
	Sycamore
3	Cypress, southern
	Redwood
4	Ash, commercial white
	Ash, Oregon
	Beech
	Birch, sweet and yellow
	Cedar, eastern red
	Cherry, black
	Douglas fir (coast region)
	Elm, rock
	Hickory, true and pecan
	Honey locust
	Larch, western
	Locust, black
	Maple (hard), black and sugar
	Oak, commercial red and white
	Pine, southern yellow
	Tamarack
	Walnut, black
5	Douglas fir (dense)
	Southern yellow pine (dense)

BULLDOG CONNECTOR

The bulldog connector (fig. 22) consists of a steel plate circular or square in shape with teeth spaced evenly along the edges at an angle of 100° with the plate. The joint is formed by placing the connector between two wood members, forcing them together, and then holding them in place with a bolt through the center of the connector. The bulldog connector is made in 6 sizes, 5 of which have teeth on both faces. The smallest are circular with diameters of 2, 3, and 3¾ inches, respectively. The largest are square, 4 by 4, and 5 by 5 inches, respectively, and have teeth at the square inside opening as well as at the outer edges. The sixth style, which is circular, is called the

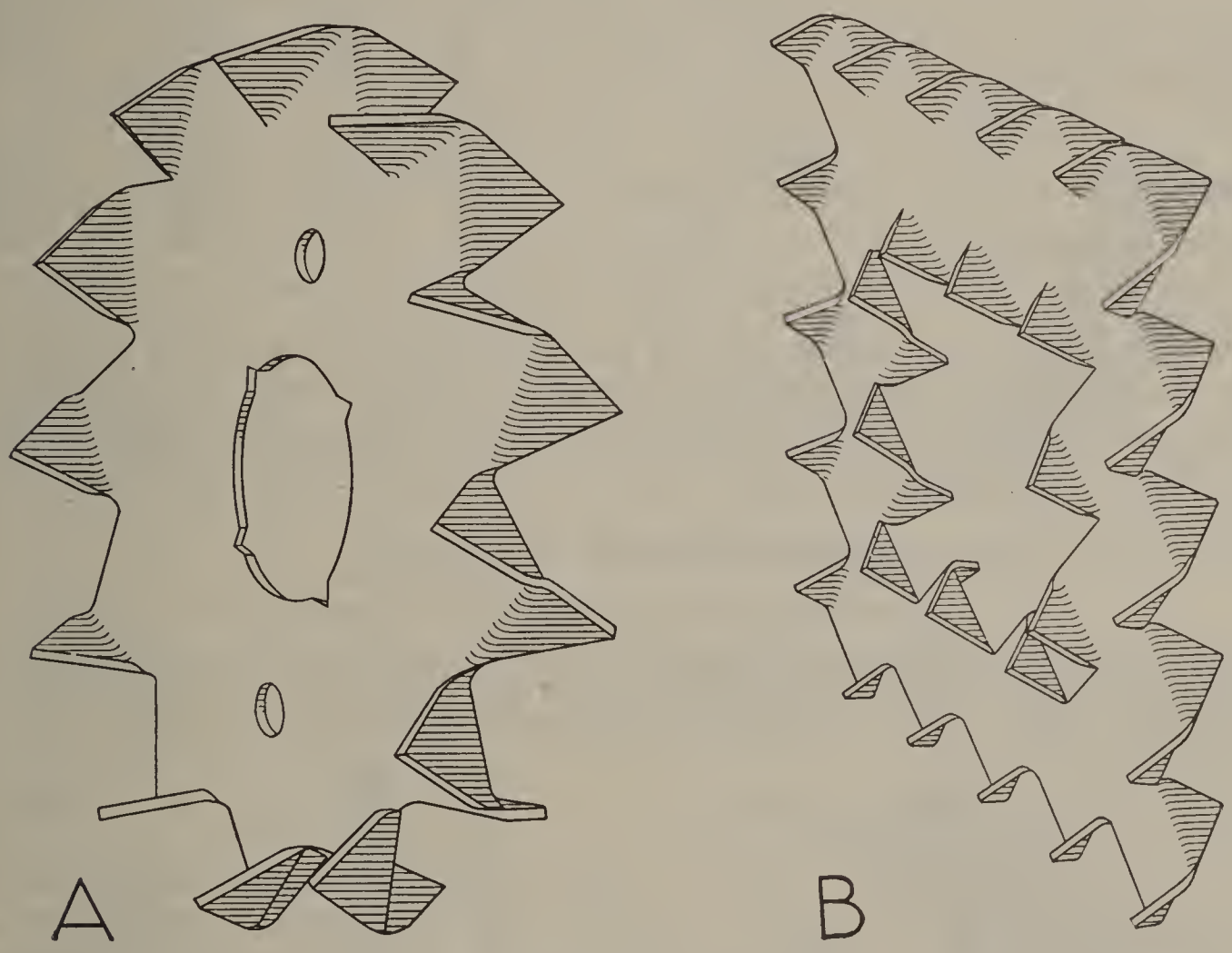


FIGURE 22.—Bulldog connectors: *A*, circular; *B*, square.

single bulldog because its teeth project from one face only. It has a hub to provide bearing against the connecting bolt. It is used as a half dowel at the bolt between a metal plate or strap and a wood member and in this way distributes the bolt-bearing stress in the wood. The thickness of metal used in the 3 and the 3¾-inch round bulldogs and in the 4 by 4 and 5 by 5 square bulldogs is 0.049, 0.053, 0.053, and 0.067 inch, respectively. The holes for the connecting bolts are bored one-eighth inch larger than the bolt diameters. The recommended working loads for two bulldog connectors symmetrically loaded, as in an assembly like figure 20, are given in table 34. These loads are based on a factor of 4 on ultimate loads of specimens tested at the Forest Products Laboratory.

Because of the relatively small difference between the safe loads for bearing parallel to the grain and those for bearing perpendicular to the grain, any scheme of adjustment for angles between these limits may be used without appreciable error.

TABLE 34.—*Safe loads with seasoned southern yellow pine or Douglas fir (coast region) timbers for 2 symmetrically loaded bulldog connectors*

Size of connector	Diameter of bolt	Safe load	
		Parellel with the grain	Perpendicular to the grain
	Inches	*Pounds*	*Pounds*
3-inch circular	3/8	2,250	2,025
	1/2	2,800	2,520
	5/8	3,420	3,080
3¾-inch circular	3/8	3,000	2,700
	1/2	3,550	3,200
	5/8	4,200	3,780
	3/4	4,900	4,410
4-inch square	1/2	4,320	3,240
	5/8	4,930	3,700
	3/4	5,530	4,150
	7/8	6,130	----------
	1	6,750	----------
5-inch square	3/4	7,300	5,470
	7/8	7,800	5,850
	1	8,200	6,150
	1¼	10,500	7,880
3¾-inch circular single	3/4	4,900	4,410

The loads given, which are for southern yellow pine and Douglas fir, may be safely used with all group 4 species listed on page 138. For group 1 species use 80 percent of these values, for group 2 use 85 percent, for group 3 use 90 percent, and for group 5 use 110 percent.

SIEMENS-BAUUNION CONNECTORS

THE SIEMENS-BAUUNION CLAW PLATE

The connector shown in figure 23 is a combination of ring dowel and claw plate. The connectors may be used singly or in pairs. The plate with a hub (fig. 24) acts as a stress distributor or half dowel between a metal plate or strap and a wood member. When used in pairs they act as full dowels in transferring load directly from one wood member to another. Each half consists of an aged cast-iron disk, 3⅛ inches in diameter, with a bolt hole in the center and teeth on one face at the rim; a hub in one plate fitting into the central hole of the other. With this hub arrangement, little or no stress, except the tension

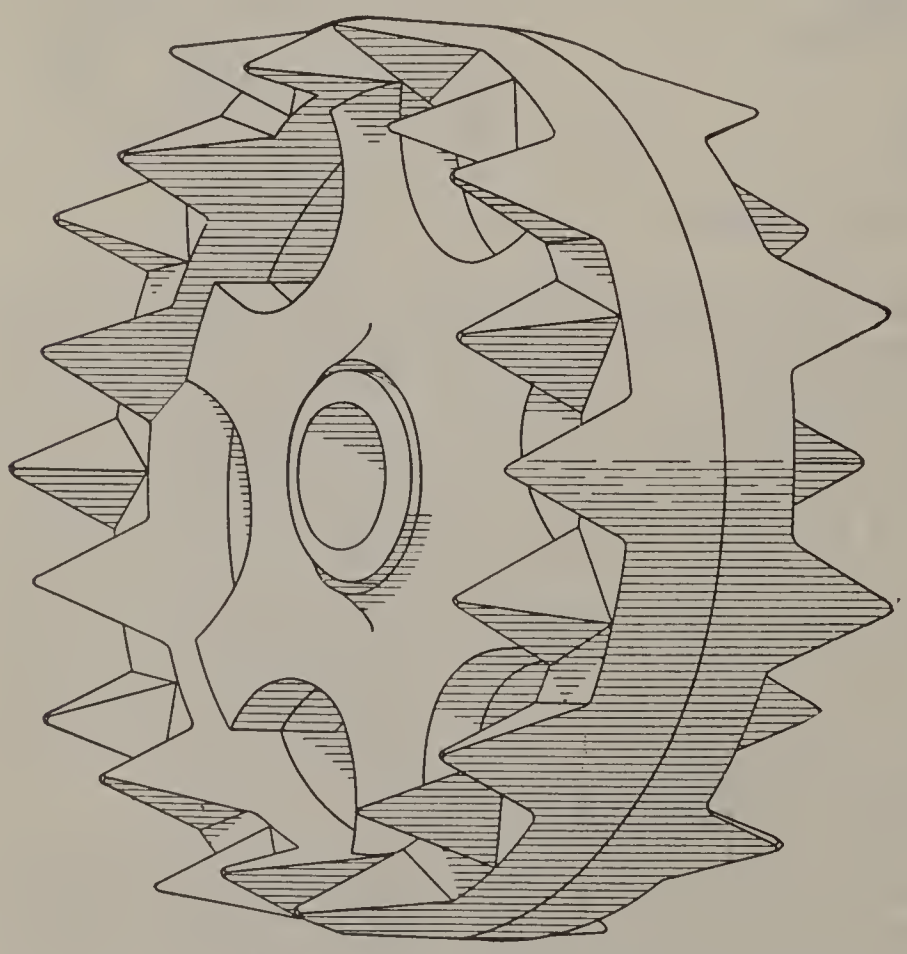


FIGURE 23.—A pair of Siemens-Bauunion connectors.

needed to hold the joint together, occurs in the bolt. Any small shrinkage in the wood members does not loosen the wood from the teeth, but instead merely causes the metal parts to separate slightly without seriously detracting from the bearing capacity of the joint.

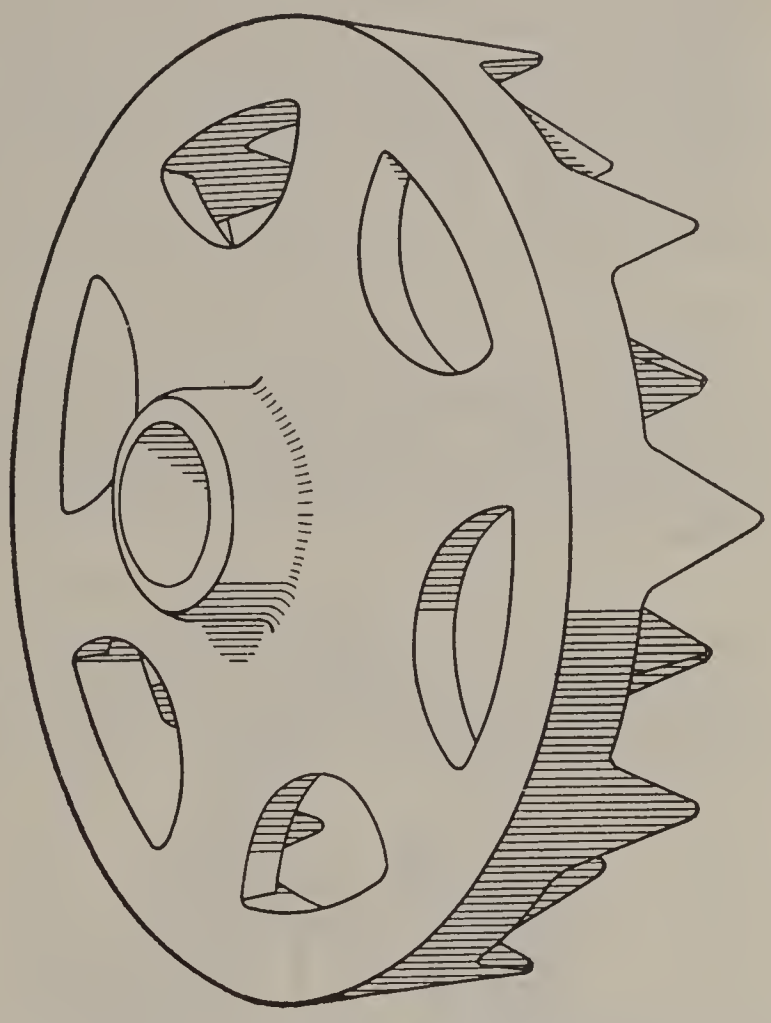


FIGURE 24.—A single Siemens-Bauunion connector plate with hub.

THE SIEMENS-BAUUNION HINGE-CONNECTOR ASSEMBLY

A hinge connector (fig. 25) for wood trusses makes it possible to stress the wood only in the direction in which it is strongest, that is, parallel to the grain. The hinge connector consists of a heavy steel ring (fig. 25, *A*) into which two or more straps of silicon steel are fitted together with a mushroom-shaped steel locking wedge (fig. 25, *B*). This permits free rotational movement of the members under the elastic deformation of a truss and transmits either tension or compression without inducing secondary stresses. Siemens-Bauunion claw plates (figs. 24 and 25, *C*) placed into the wood on both faces transmit load from the wood members to the steel straps. The metal rings (fig. 25, *A*) of the hinge connector are made in two sizes, 4⅛ and 5⅞ inches in diameter. The manufacturers recommend a safe load of 26,500 pounds for the smaller ring and 53,000 pounds for the larger ring. These loads limit the number of pairs of claw plates that can be safely used with each size. A safe load of 6,400 pounds is recommended by the Forest Products Laboratory for two symmetrically loaded Siemens-Bauunion claw-plate connectors when

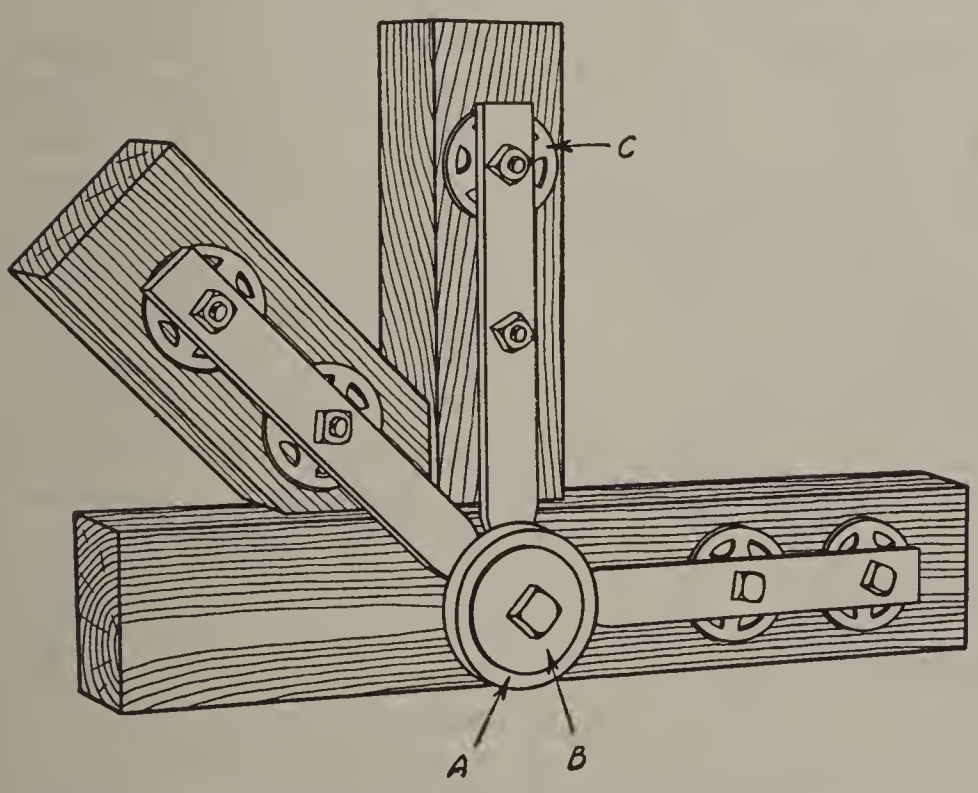


FIGURE 25.—Siemens-Bauunion hinge-connector assembly: *A*, Heavy steel ring; *B*, mushroom-shaped locking wedge; *C*, claw plate.

placed between metal straps and a central timber and bearing parallel to the grain. This load applies to all group 4 woods listed on page 138, and is based on a factor of 4 on ultimate loads of specimens tested at the Forest Products Laboratory. When male and female connectors are used in pairs between a center timber and wood side plates, a safe load of 5,250 pounds is recommended for two such pairs symmetrically loaded and bearing parallel to the grain.

The factor to be applied to the loads recommended above when the bearing is at an angle other than 0° with the grain is:

For 22½°, 0.95; for 45°, 0.84; for 67½°, 0.75; and for 90°, 0.72.

The recommended loads just given are for all group 4 species listed on page 138. For group 1 species use 65 percent of these values, for group 2 use 75 percent, for group 3 use 85 percent, and for group 5 use 115 percent.

G. S. CIRCULAR SPIKE CONNECTOR

While the description and data given here are for circular spike connectors, it is reported that the European manufacturers plan to change the design from the circular to a rectangular form.

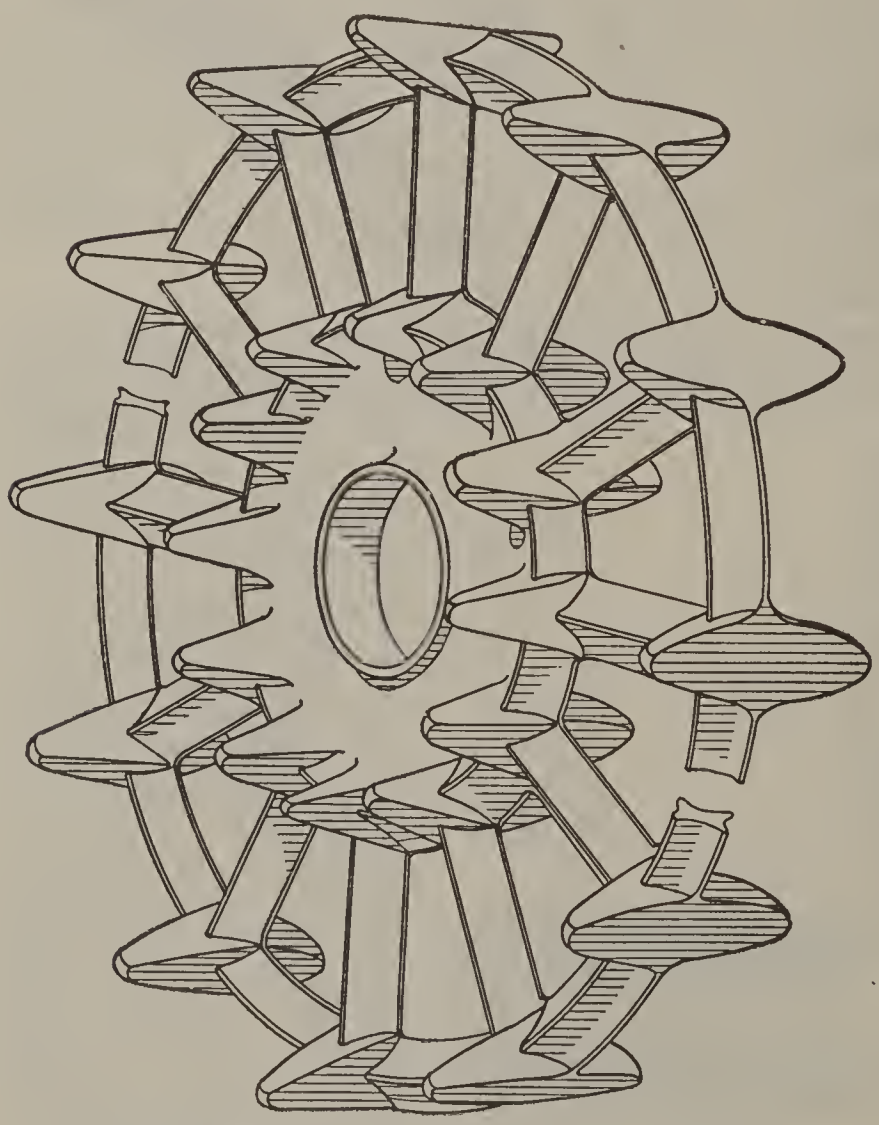


FIGURE 26.—G. S. circular spike connector.

The G. S. circular spike connector (fig. 26) is a casting $4\frac{5}{16}$ inches in diameter with teeth $1\frac{1}{16}$ inches from tip to tip. Twelve arms extend radially from a central circular plate about 2 inches in diameter to an outer ring with a tooth at each end of each arm and on each face. The central plate is cored for the bolt. A three-fourth inch connecting bolt is used with this type of connector. In the tests made at the Forest Products Laboratory and upon which the safe loads given below are based, the diameter of the bolt hole was made the same as the diameter of the bolt. The recommended working load for two G. S. circular spike connectors symmetrically loaded, as in an assembly like figure 20, are 10,200 pounds for bearing parallel to the grain and 6,800 pounds for bearing perpendicular to the grain in group 4 woods on page 138. The loads are based on a factor of 4 on ultimate

loads of specimens tested at the Forest Products Laboratory. For bearing at angles between 0° and 45° with the grain, the safe load should be reduced uniformly from that for bearing parallel to the grain to that for bearing perpendicular to the grain and remain constant for angles from 45° to 90°.

The loads just given are for all group 4 species listed on page 138. For group 1 species use 80 percent of these values, for group 2 use 85 percent, for group 3 use 90 percent, and for group 5 use 110 percent.

LOCHER INTEGRAL SPLIT-RING CONNECTOR

The Locher split-ring connector (fig. 27) is a gray-iron casting cut at one point at approximately 35° with a diametral line. The inclination of the cut is to provide end surfaces that will bear on each other for an appreciable travel, so that the ring may adjust itself readily to shrinkage, without damage to the wood walls of the grooves. The ring is thicker at its middle, its inner surface tapering uniformly to each edge. The grooves in the timbers to be connected should be 2 or 3 percent larger in diameter than the ring, which requires that the rings be spread and forced into place. The initial stresses thus developed in the ring will be relieved if shrinkage occurs; if swelling should occur the ring will still fit. The thickened portion in the middle of the ring increases the resistance against distortion, especially under excessive loads that might shear off the inner wood core, and may increase somewhat the resistance against overturning.

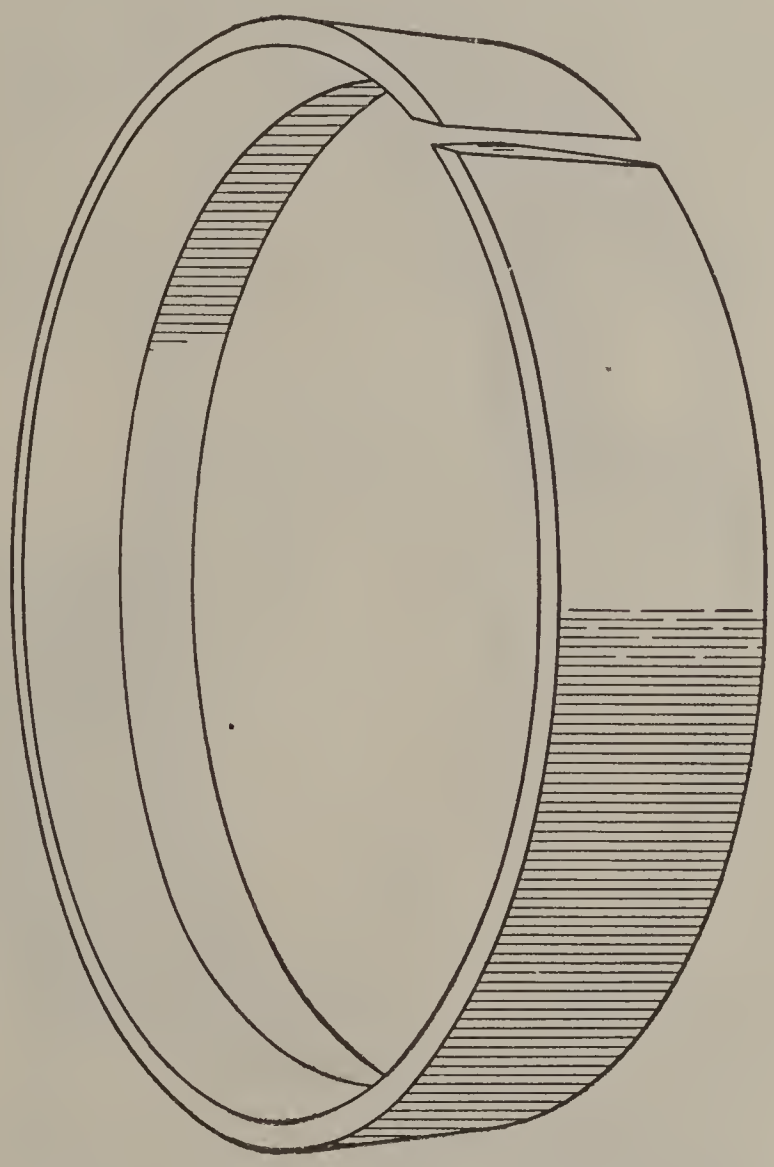


FIGURE 27.—Locher integral split-ring connector.

Three sizes of rings were tested at the Forest Products Laboratory, 4, 5½, and 8 inches in diameter, respectively. A three-fourths-inch connecting bolt was used with all sizes. The depth of the smallest ring was $1\frac{3}{16}$ inches, that of the 5½-inch ring 1⅝ inches, and that of the 8-inch ring also 1⅝ inches. The recommended working load for two rings bearing symmetrically in the group 4 woods on page 138, as in an assembly like figure 20, *A*, are 11,500 pounds for the 4-inch rings, 15,000 pounds for the 5½-inch rings, and 20,000 pounds for the 8-inch rings. The recommended working load for two rings bearing perpendicular to the grain, as in an assembly like figure 20, *B*, are 9,200

pounds for the 4-inch rings, 10,500 pounds for the 5½-inch rings, and 10,500 pounds for the 8-inch rings. A lineal variation between the safe loads for bearing parallel to the grain and those for bearing perpendicular to the grain is recommended for angles between these two limits. These loads are for all the group 4 species listed, and are based on a factor of 4 on ultimate loads of specimens tested at the Forest Products Laboratory. For group 1 species, use 65 percent of these values, for group 2 use 75 percent, for group 3 species use 85 percent, and for group 5 woods use 115 percent.

LOCHER TWO-PIECE RING CONNECTOR

The Locher two-piece ring (fig. 28) was designed with an S-shaped hinged joint opposite the split, so that the ring will open or close, thus eliminating secondary stresses in the ring itself. The installation of the two-piece ring is similar to that of the integral ring, in that the grooves are made slightly larger in diameter than the rings. Two sizes of two-piece ring connectors were tested at the laboratory, one 5½ inches in diameter, the other 8 inches. The recommended loads are the same as those for the integral rings of corresponding sizes.

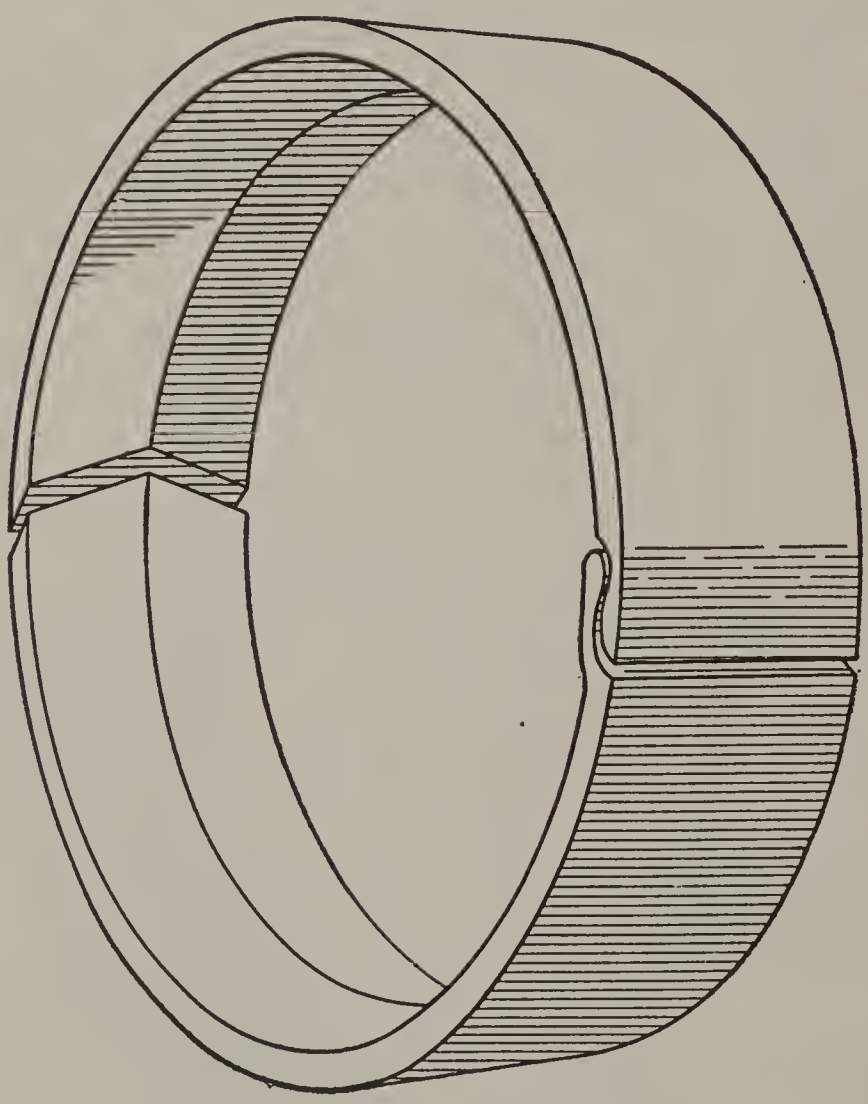


FIGURE 28.—Locher two-piece ring connector.

THE TUCHSCHERER (VOSS) SPLIT RING

The Tuchscherer split ring (fig. 29), now manufactured and sold in the United States under an American trade name, is a one-piece ring with a tongue and groove at the split. Unlike the Locher rings, these rings are of uniform thickness. The installation is similar, however, in that the grooves in the wood are made slightly larger in diameter than the rings. Working loads recommended by the manufacturer are given in table 35.

These loads are based on a factor of 3.5 on ultimate loads or 1.6 on proportional limit load of specimens tested at the Forest Products Laboratory, whichever gave the smaller load. Such recommendations are more conservative than those used by engineers in foreign countries where connectors were developed and have been largely used. No increase of the loads shown herein is recommended for wind or earthquake load design. If intermittent loads, such as wind or earthquake, are of relatively little importance the Forest

Products Laboratory recommends a factor of 4 rather than 3½, that is, working loads seven-eighths those shown in table 35.

TABLE 35.—*Manufacturers' recommended safe loads for 2 symmetrically loaded Tuchscherer split rings*

Inside diameter of ring (inches)	Depth of ring	Diameter of bolt	Safe load					
			Douglas fir (coast region), western larch, southern yellow pine, and tamarack		Cypress and redwood		"Dense" Douglas fir and southern yellow pine	
			Parallel with grain	Perpendicular to grain	Parallel with grain	Perpendicular to grain	Parallel with grain	Perpendicular to grain
	Inches	*Inch*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
2½	0.75	½	5,700	4,000	4,800	3,300	6,600	4,700
4	1.00	¾	12,000	8,400	10,000	7,000	14,000	9,800
6	1.25	¾	18,000	10,800	15,000	9,000	21,000	12,600
8	1.50	¾	23,000	11,500	19,000	9,600	27,000	13,400

A lineal variation between the safe loads for bearing parallel with the grain and those for bearing perpendicular to the grain is recommended for angles between these two limits.

Loads are given for group 3, 4, and 5 woods listed on page 138. For group 1 species use 65 percent of the values given in the table for Douglas fir (coast region), western larch, southern yellow pine, and tamarack, and for group 2 woods use 75 percent.

KÜBLER WOOD DOWEL

The Kübler doubly coned dowels (fig. 30) were originally made of cast iron. Later oak was tried and found satisfactory in Europe. Two sizes were tested by the laboratory, one approximately 2½ and the other approximately 4 inches in diameter. Bolts one-half inch in diameter were used with each size, and the bolt holes in the test specimens were bored one-sixteenth inch larger than the bolts.

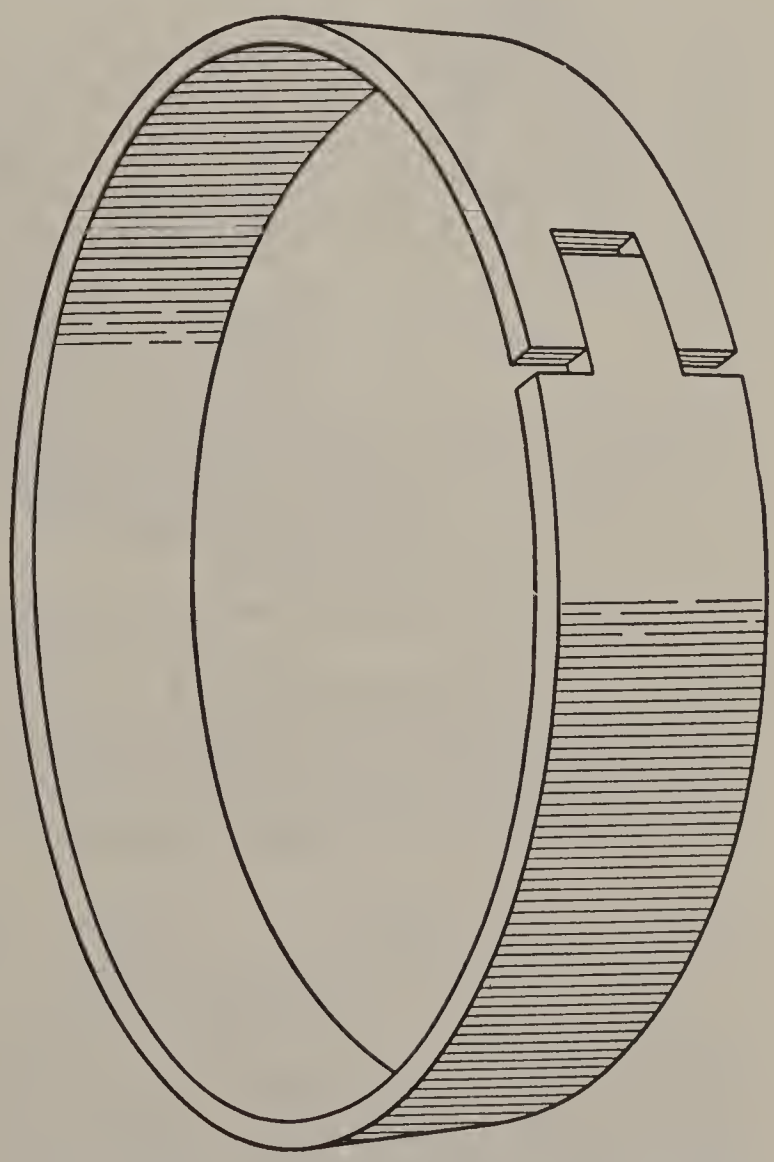


FIGURE 29.—Tuchscherer split-ring connector.

The recommended working load for two Kübler wood dowels symmetrically loaded, as in an assembly like figure 20, are given in table 36.

TABLE 36.—*Recommended working loads for Kübler wood dowels*

Size of dowel (inches)	Parallel	Perpendicular
2½	1,650	990
4	3,750	1,425

These loads are for oak dowels used in seasoned southern yellow pine or Douglas fir (coast region). They may be safely used with all the group 4 species listed on page 138, and are based on a factor of 4 on ultimate loads of specimens tested at the Forest Products Laboratory. For group 1 woods use 80 percent of these values, for group 2 use 85 percent, for group 3 use 90 percent, and for group 5 use 110 percent.

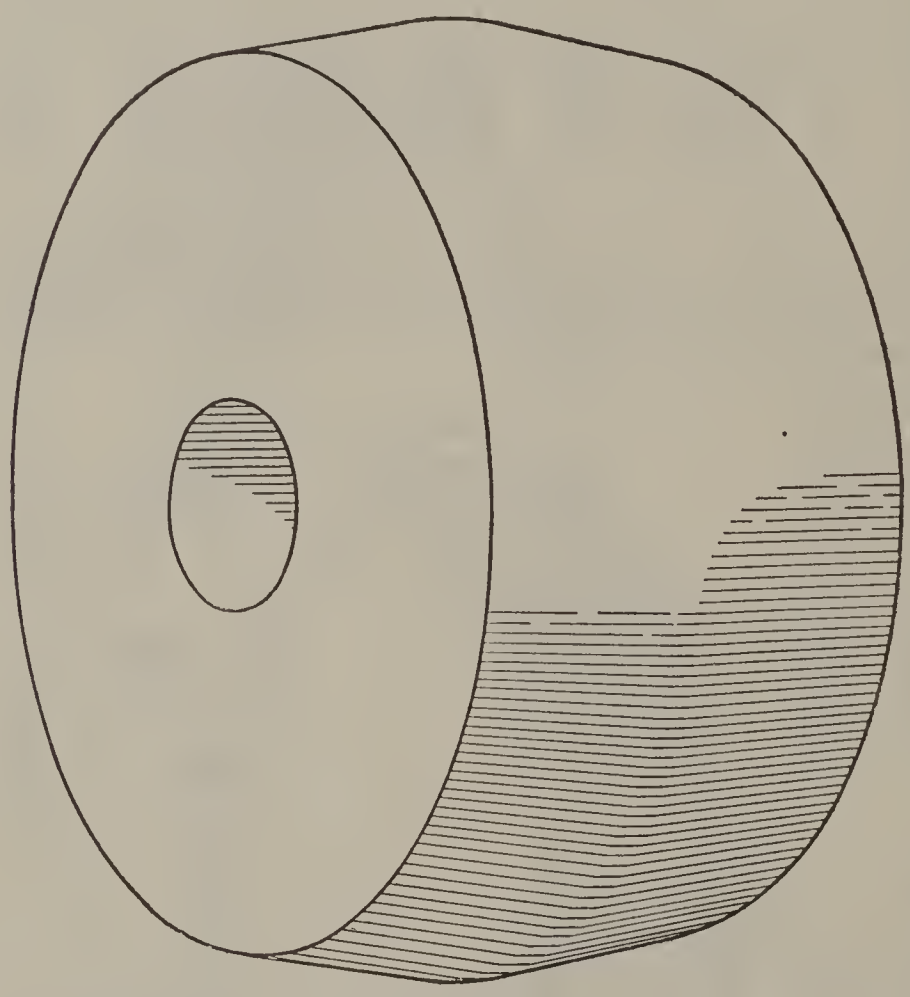


FIGURE 30.—Kübler wood-dowel connector.

DETAILS OF DESIGN

All the loads given in the preceding pages for the various connectors assume ample clearance from the edges of the connectors to the end or side of the timber in which they are inserted and an adequate spacing center to center of connectors in the same piece. To date the Forest Products Laboratory has tested only the Tuchscherer split ring, manufactured in the United States, to determine minimum requirement in these respects. The following tentative conclusions are based upon the results of these tests.

EDGE MARGIN

The 2½-, 4-, 6-, and 8-inch rings may be used in nominal lumber widths of 4, 6, 8, and 10 inches, respectively, when the load is applied parallel to the grain or at an angle up to 30° with the grain.

Safe loads parallel and perpendicular with the grain are given in table 35. Loads applicable to angles between 0° and 90° may be obtained by interpolation.

When the angle of load to the grain exceeds 30° in any member of a timber joint the loads must be reduced unless the edge margin is at least 1½ inches, measured from the outside edge of the groove to the edge of the timber. The minimum edge margins permitted are those resulting when 2½-, 4-, 6-, and 8-inch rings are placed in the middle of the face of nominal 4-, 6-, 8-, and 10-inch material, respectively. This results in edge margins of from three-tenths to five-tenths inch, depending upon the size of ring. When these minimum margins are used the loads must be reduced 15 percent. Loads applicable for edge margins between 1½ inches (where no reduction in load is required for margin) and the minimum edge margins, should be reduced proportionately between these limits.

End Margin

The distance from the outside edge of a ring groove to the end of a timber should be 1½ inch greater than half the ring diameter, that is, $\frac{D}{2}$ + 1½ inch. If the end margin is reduced below this minimum, the safe load must also be reduced and proportionately to 67 percent when the end margin as described is 1 inch. End margins less than 1 inch are not recommended for either compression or tension members.

Spacing of Split Rings

The spacing center to center of split rings in the same piece with load applied parallel with the grain should be not less than 1½ diameters. When the load is applied perpendicular to the grain the spacing of rows of rings should be sufficient to afford at least one-half inch of wood between the outer edges of adjacent ring grooves.

Minimum Lumber Dimensions and Groove Sizes

The minimum thickness and width of lumber in which split rings may be used and recommended sizes of groove dimensions are given in table 37.

Table 37.—*Minimum lumber dimensions and groove sizes for split rings recommended by the manufacturers*

Inside diameter of ring when closed (inches)	Actual lumber dimensions			Groove dimensions		
	Minimum width	Minimum thickness		Inside diameter of groove	Width of groove	Depth of groove
		Rings in opposite faces	Rings in 1 face			
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
2½	3⅝	2⅝	1 5/16	2.56	0.18	0.37
4	5½	2⅝	1⅝	4.08	.21	.50
6	7½	3⅝	2⅛	6.12	.27	.62
8	9½	4½	2⅝	8.14	.34	.75

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WOOD BEAMS, COLUMNS, AND ARCHES

SOLID BEAMS OF RECTANGULAR SECTION

In timber construction beams are usually of rectangular section and of uniform depth throughout the span. They should be so designed that the following stresses do not exceed the allowable unit values: (1) The extreme fiber stress caused by transverse loads; (2) the maximum horizontal shear stress; and (3) the stress in compression across the grain at the end bearings. Furthermore, they should also be so designed that the deflection will not exceed the limit fixed by the use to which the structure is to be put. Each of these factors is discussed in the following paragraphs.

EXTREME FIBER STRESS

Either the ultimate bending strength or the safe load for a wood beam of rectangular cross section may be calculated by substitution of appropriate values in the formula

$$M=\frac{sI}{c}$$

in which M is the bending moment, s the extreme unit fiber stress, I the moment of inertia of the section about the neutral axis, and c the distance from the neutral axis to the extreme fiber, all dimensions being in inches. For a rectangular beam b wide and d deep, the preceding formula reduces to

$$M=\frac{sbd^2}{6}$$

If the ultimate bending strength is desired, s is the modulus of rupture. If a safe load is desired, s is the safe extreme fiber stress for the kind and grade of material used. In either case, M must be expressed in terms of the load and the span in order to calculate the load. For example, with a simply supported beam having a total load W uniformly distributed over a span L

$$M=\frac{WL}{8}$$

and with a concentrated load P at the center of the span

$$M=\frac{PL}{4}$$

As pointed out, under Duration of Stress (p. 62), a wood beam will carry a much greater load for a few minutes than for a period of months or years. For this reason impact stresses in amounts up

to the live load stresses may be neglected in the design of wood beams and stringers, since such members will safely sustain the additional stress for the short period involved.

HORIZONTAL SHEAR IN BEAMS

Small beams free from shakes, checks, and splits practically never fail by shear, but ordinarily beams even of small size are not entirely free of all such defects. When present, there is a concentration of stress at the bottom of such openings, and it is this concentration that causes shear failures at relatively low stresses calculated on the reduced section.

The recommended safe stresses of table 20 assume that checking sufficient to cause high concentration of stress exists.

SHEAR IN CHECKED BEAMS

In setting up safe shear stresses a certain depth of check or shake at the neutral plane is permitted in one grade and a different depth in another grade; the allowable shear stress, which assumes calculation on the full width of the beam, is modified accordingly.

The customary shear formula is

$$q=\frac{VQ}{It}$$

in which all units are in inches or pounds and q represents the maximum horizontal shear stress; Q, the statical moment of the area either above or below the neutral axis and about that axis (as here used statical moment is a product of an area and the distance from the center of gravity of that area to an axis.); V, the external shear; I, the moment of inertia of the section about the neutral axis; and t, the width of beam at the neutral axis.

With a rectangular beam b wide and d deep, the formula reduces to

$$q=\frac{3V}{2bd}$$

Because the upper and the lower portions of a beam checked near the neutral plane act partly as two beams and partly as a unit, a part of the end reaction V is resisted internally by each half of the beam acting independently and consequently is not associated with shearing stress at the neutral plane (Newlin, Heck, and March). In using this formula in which b is the full width of the beam and q the allowable shear stress based on the assumption that checks are present, allowance for two-beam action must be made in calculating the reaction V.

The following procedure is recommended for calculating the horizontal shear on the neutral plane in checked beams.

Use the ordinary shear formula as just given.

Use for the safe shearing stress the value given for safe working stresses in table 18.

In calculating the reactions for use in the formula (1) take into account any relief to the beam under consideration resulting from load being distributed to adjacent parallel beams by flooring or

other members of the construction, (2) neglect all loads within the height of the beam from both supports, (3) if there are any moving loads, place the largest one at three times the height of the beam from the support, (4) treat all other loads in the usual manner, and (5) if a timber does not qualify for shear resistance under the foregoing procedure, which under certain conditions may be over-conservative, the reactions for the concentrated loads should be more accurately determined by the following equation:

$$r' = \frac{10P'(L - x')\left(\frac{x'}{h}\right)^2}{9L\left[2 + \left(\frac{x'}{h}\right)^2\right]}$$

in which r' is the reaction to be used as due to a load P'; L, the span in inches; x', the distance in inches from the reaction to the load P'; and h, the height of beam in inches.

COMPRESSION ACROSS THE GRAIN

The end-bearing area A should be such that the reaction V divided by A will not exceed the allowable stress given in table 18 of safe working stresses. The bearing stresses perpendicular to the grain given in this table apply to bearings of any length at the ends of a beam and to bearings 6 inches or more in length at any other place along the beam. They may be increased when applied to small plates, washers, and so forth, as explained on page 104. In calculating the bearing area at the ends of beams, no allowance need be made for the fact that as the beam bends the pressure upon the inside edge of the bearing is greater than at the opposite edge.

DEFLECTION LIMITATIONS

When service conditions require that beams be designed for stiffness, the dimensions must be calculated by means of the usual deflection formulas and the deflection kept within a prescribed fraction of the span. For plastered ceilings the deflection is usually limited to one three-hundred sixtieth of the span. A ratio of one two-hundredths of the span has been used for highway bridges, but some engineers advocate a more severe limitation. A commonly recorded limitation for stringers in railroad bridges and trestles is one three-hundredths of the span. For floors that support shafting, deflection limitations much more severe than the preceding are sometimes required.

Wood beams usually sag in time, that is, the deflection increases beyond what it was immediately after the load was first applied. This is especially true of green timbers allowed to season under load, although partially seasoned material will also sag to some extent. After thorough seasoning there are small changes in deflection with changes in moisture content, but only little permanent increase in deflection.

To make allowance for the sag discussed in the previous paragraph, it is customary to double the dead load, but not the live load, when computing the deflection.

NOTCHED BEAMS

Beams are often notched at the ends to cut down clearance or to bring the top surfaces level with adjacent beams (fig. 31). Occasionally they are also notched at intermediate points, either bottom or top, in order to clear other parts of a structure or to receive other members.

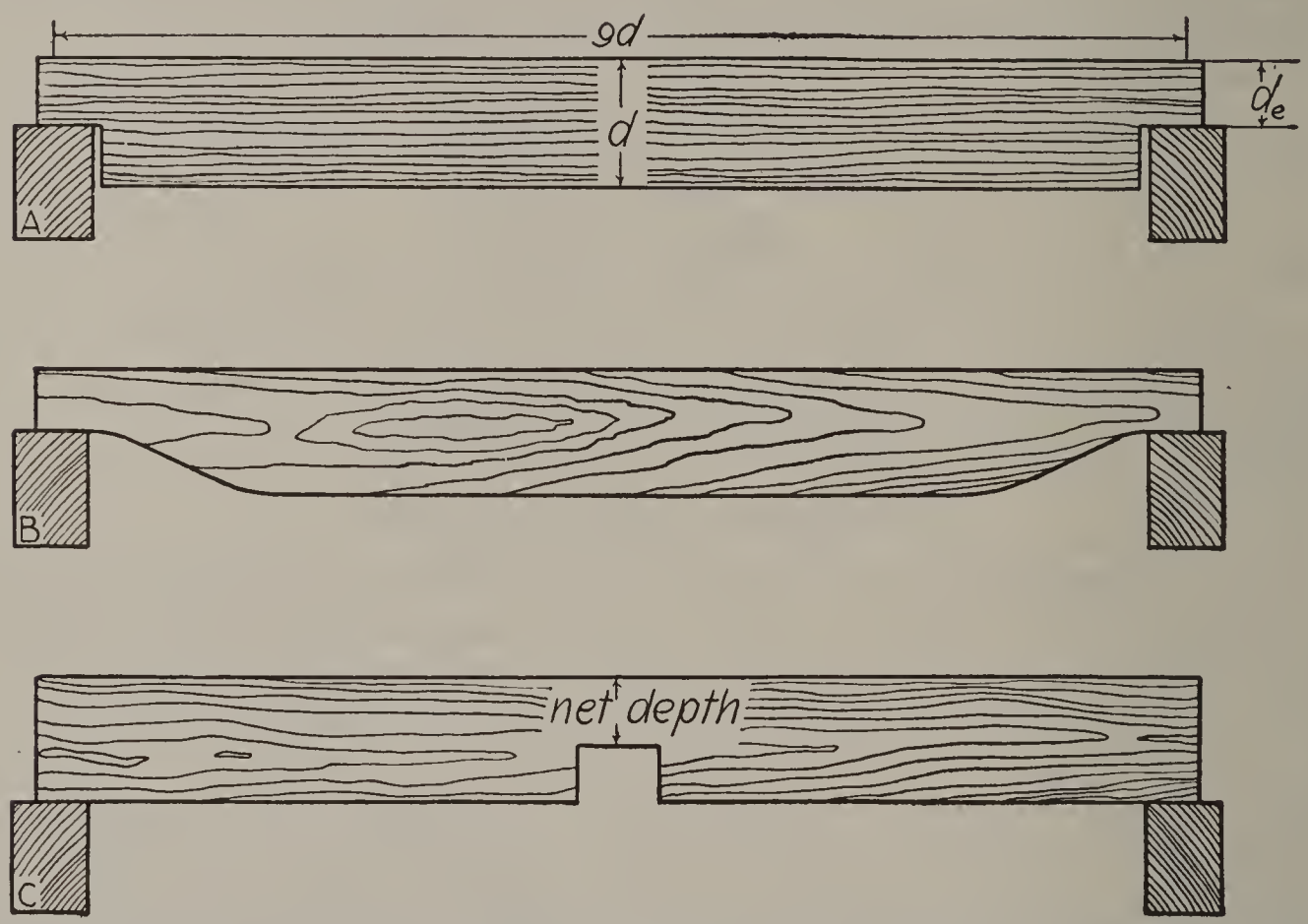


FIGURE 31.—Notched beams: *A*, Notched at ends to half its depth; *B*, beam with gradual change in cross section at ends to eliminate concentration of stress; *C*, notched to half its depth at center.

When notched on the lower side at the ends, the strength of a short, relatively deep beam is decreased by an amount depending on the shape of the notch and on the relation of the depth of the notch to the depth of the beam. It is recommended that in designing beams with square-cornered notches at the ends of the beams the desired bending load be checked against the load obtained by the equation

$$V=\frac{2}{3}\left(\frac{bd_e^2q}{d}\right)$$

where V=the end reaction; b=the width; d_e=the actual end depth above the notch; d=the total depth of beam; q=the working stress in horizontal shear.

In setting up this equation the actual end depth is used as the effective depth to resist shear and the safe shear stress is reduced by multiplying it by the ratio of the effective depth to the total depth. Experiments made at the laboratory substantiate this recommendation. Experiments also showed that by cutting away the lower corner at the end notches to obtain a gradual change in cross section, the breaking loads were raised very markedly (fig. 31, *B*).

When notches are at or near the middle of the beam the net depth should be used in determining the bending strength. Tests have

shown that as far as breaking loads are concerned this rule is sufficiently conservative. However, the general tendency of a notch on the top or bottom of a beam and near the point of maximum moment is to lower the proportional-limit load and to start compression or tension failure at lower loads than would be expected of an unnotched beam of a depth equal to the net depth of the notched beam.

The stiffness of a beam is practically unaffected by notches.

FORM FACTOR OF RECTANGULAR BEAMS

When the height of a beam of rectangular cross section is increased, the modulus of rupture decreases slightly, and this decrease should be considered in accurate comparisons of beams of different heights (Newlin and Trayer).[29] The fractional decrease is the difference between unity and the form factor of the beam. A form factor is the ratio of the unit strength value of a beam of structural size to the corresponding unit value for a beam 2 by 2 inches in cross section. In the investigative work at the laboratory the form factor of all test beams of structural size used in determining working stresses in extreme fiber in bending was taken for simplicity as 90 percent, which corresponds approximately to a beam height of 12 inches; thus the form factor is already included in the safe stresses in bending that the laboratory recommends, and for ordinary purposes need not be considered further. In addition to test results for beams of structural size, corresponding results for small clear specimens having a form factor of unity are considered in determining working stresses.

The form factor, F, is inserted in the usual beam formula as follows:

$$M=\frac{FsI}{c}$$

in which M represents the bending moment; s, the unit stress due to the bending moment upon the fiber most remote from the neutral axis; I, the moment of inertia of the cross section about the neutral axis; c, the normal distance from the neutral axis to the outermost fiber. For a rectangular beam this formula reduces to

$$M=\frac{Fsbd^2}{6}$$

in which b represents the breadth of the beam and d represents the depth of the beam. The value of F is calculated by means of the formula

$$F=1-0.07\left(\sqrt{\frac{d}{2}}-1\right)$$

in which d is the depth of the beam. The value of F becomes unity when d is equal to 2. All standard bending tests on clear wood are made on beams 2 by 2 inches in cross section and the formula for F was accordingly based on the value of the factor, unity, for a 2-inch height.

[29] For further information, the references at the end of this section should be consulted.

I AND BOX BEAMS

Though beams of rectangular section are by far the most common in timber construction, beams with I and box sections are sometimes used. Such beams are usually built up with the joints glued. Laminated arches are often made with such sections, particularly in Europe. Such design places a large portion of the cross-sectional area away from the neutral plane of bending, thereby increasing the moment of inertia of the section which theoretically should increase the resistance to bending. This is efficient practice with metal, but with wood the net gain in bending strength is small because when the form of the cross section is changed the extreme fiber stress changes also. Although the gain in bending strength for a given cross-sectional area may not be important, the increase in overall width by using I and box sections may often be decidedly advantageous because of the increase in the resistance of the beam to lateral buckling.

The reduction in extreme fiber bending stress for I and box sections can be calculated, and it is necessary to do so with such design since the safe extreme fiber stresses for wood beams apply directly only to beams of rectangular section. The reduction factor for the modulus of rupture may be obtained by substituting in the following empirical formula:

$$F=0.50+0.50\left(\frac{K(t_2-t_1)}{t_2}+\frac{t_1}{t_2}\right)$$

in which F represents the form factor for modulus of rupture; K, a coefficient depending upon the ratio of flange depth to total depth of beam; t_1, the thickness of the web of an I beam or the combined thickness of the two webs of a box beam; and t_2, the overall width of beam.

Values of K in the form factor formula are as follows:

Ratio of depth of compression flange to depth of beam:	*Values of K*
0.10	0.085
0.15	.155
0.20	.230
0.25	.315
0.30	.400
0.35	.490
0.40	.575
0.45	.660
0.50	.740
0.55	.810

Ratio of depth of compression flange to depth of beam—Continued.	*Values of K*
0.60	0.875
0.65	.920
0.70	.950
0.75	.970
0.80	.985
0.85	.995
0.90	.998
0.95	1.000
1.00	1.000

The form factor F is applied as a multiplying factor in the ordinary beam formula thus:

$$M=\frac{FsI}{c}$$

in which M represents the bending moment; s, the unit stress due to the bending moment upon the fiber most remote from the neutral axis; I, the moment of inertia of the cross section about the neutral axis; c, the normal distance from the neutral axis to the outermost fiber.

The form factor for fiber stress at proportional limit is not the same as the modulus of rupture form factor. It is obtained by substituting in the formula

$$F_1 = 0.58 + 0.42\left(\frac{K(t_2 - t_1)}{t_2} + \frac{t_1}{t_2}\right)$$

in which K has the values tabulated on page 154.

BEAMS OF CIRCULAR SECTION AND OF SQUARE SECTION WITH A DIAGONAL VERTICAL

Such wood members as poles and masts usually have circular cross sections, and sometimes ordinary beams and columns are of circular section. For architectural effects a wood beam of square section is sometimes placed with a diagonal of the section vertical. In calculating the bending strength of such members, it is necessary to include a form factor in the beam formula.

The modulus-of-rupture form factor of a circular section is 1.18, and the beam formula for a beam of circular section is written

$$M = \frac{1.18sI}{c}$$

in which M represents the bending moment; s, the unit stress due to the bending moment upon the fiber most remote from the neutral axis; I, the moment of inertia of the cross section about the neutral axis; and c, the normal distance from the neutral axis to the outermost fiber, which in this instance is equal to the radius.

The modulus-of-rupture form factor of a square section, so oriented that a diagonal of the section is vertical, is 1.414, and the beam formula for this condition is written

$$M = \frac{1.414\ sI}{c}$$

It can be shown from these formulas that a beam of square cross section has the same bending strength whether placed in the usual manner or with a diagonal of the section vertical and that a circular beam has the same strength as a square beam having the same cross-sectional area.

BUILT-UP BEAMS

Beams are sometimes built up from material of relatively small dimensions in order to (1) utilize small material, (2) reduce seasoning defects, and (3) eliminate knots and other natural defects. Two general methods are employed: (1) Several pieces of the same depth, but relatively thin, may be placed side by side and spiked or bolted together either with or without intervening spaces; (2) two or more pieces of the same width may be placed on top of each other and bolted together with keys to take the shear, or glued, or fastened together by a continuous diagonal sheathing of boards or planks well spiked to the sides of the main timbers.

LAMINATED BEAMS (LAMINATIONS VERTICAL)

Laminated beams with the laminations vertical and bolted together were found in tests at the Forest Products Laboratory to be as strong and stiff as solid beams of the same external dimensions (Heck). The laminated beams tested consisted of five nominal 2 by 12 inch planks each 16 feet long fastened together side by side with bolts spaced as indicated in figure 32. They were practically free from such defects as knots, but about one-half of the pieces contained seasoning checks. The solid beams were dense and of a high structural grade.

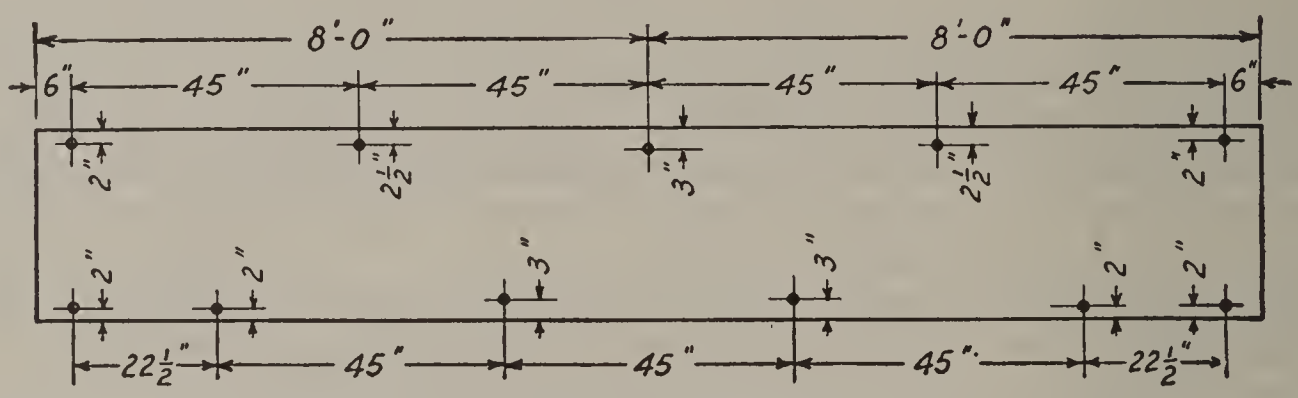


FIGURE 32.—Bolt spacing of beams with vertical laminations used in tests at the Forest Products Laboratory.

As a rule, the stiffer planks in a beam of this type take a larger percentage of the load than those less stiff. Furthermore, a piece of high stiffness will deflect farther to the proportional limit and to the maximum load than a less stiff piece. This being true, it is apparent that the first failure in a laminated beam will be in a plank of low stiffness rather than in a stiffer plank even though the latter carries a larger share of the load. This is not true of material with large defects, however, for in this instance the first failure will usually occur in the most defective piece.

It is necessary to fasten the pieces together thoroughly to prevent buckling of individual planks. If spikes are employed it is good practice also to provide some through bolts or bolts and modern connectors. Spikes are seldom used for beams more than 10 inches in depth without through bolts. It is good practice to place two bolts at each end of the beam as shown in figure 32.

SHEATHED COMPOUND BEAMS

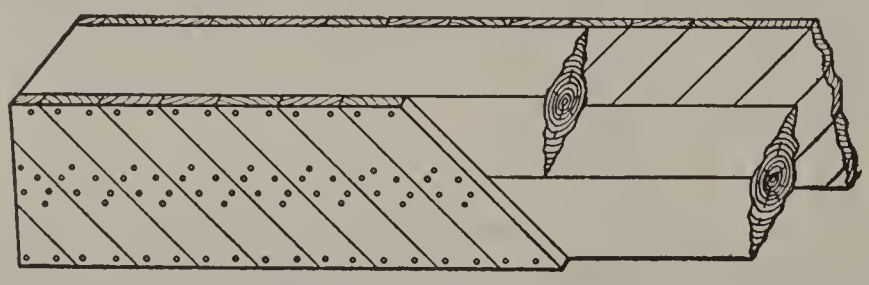


FIGURE 33.—A compound beam composed of diagonal boards or planks nailed to each side of two timbers.

A simple form of compound beam consists of diagonal boards or planks nailed to each side of two timbers placed one on top of the other (fig. 33). The diagonal sheathing runs in opposite directions on the two sides. Tests by Kidwell showed that for a span depth of 12 to 1 the efficiency of these beams was about 70 percent and for a ratio of 24 to 1 about 80 percent as regards strength. Deflections, however, were about double those of solid beams of the same size.

Kidwell reports that long before a beam broke the diagonals split open or the nails were partly drawn out or bent over in the wood,

thereby permitting the two timbers to slide on each other. Beams of this type should not be used where the increased deflection would be objectionable.

KEYED BEAMS

In a keyed compound beam the shear between adjacent timbers is taken by wood or metal keys and the timbers fastened together by bolts as in figure 34. The laboratory has not tested any beams of this type, but Kidwell tested several types of keyed beams and recommends that for ordinary purposes an efficiency of 75 percent be allowed when oak keys are used and 80 percent when cast-iron keys are used. Kidwell gives formulas for the number and spacing of keys. This information may also be found in most books on timber framing.

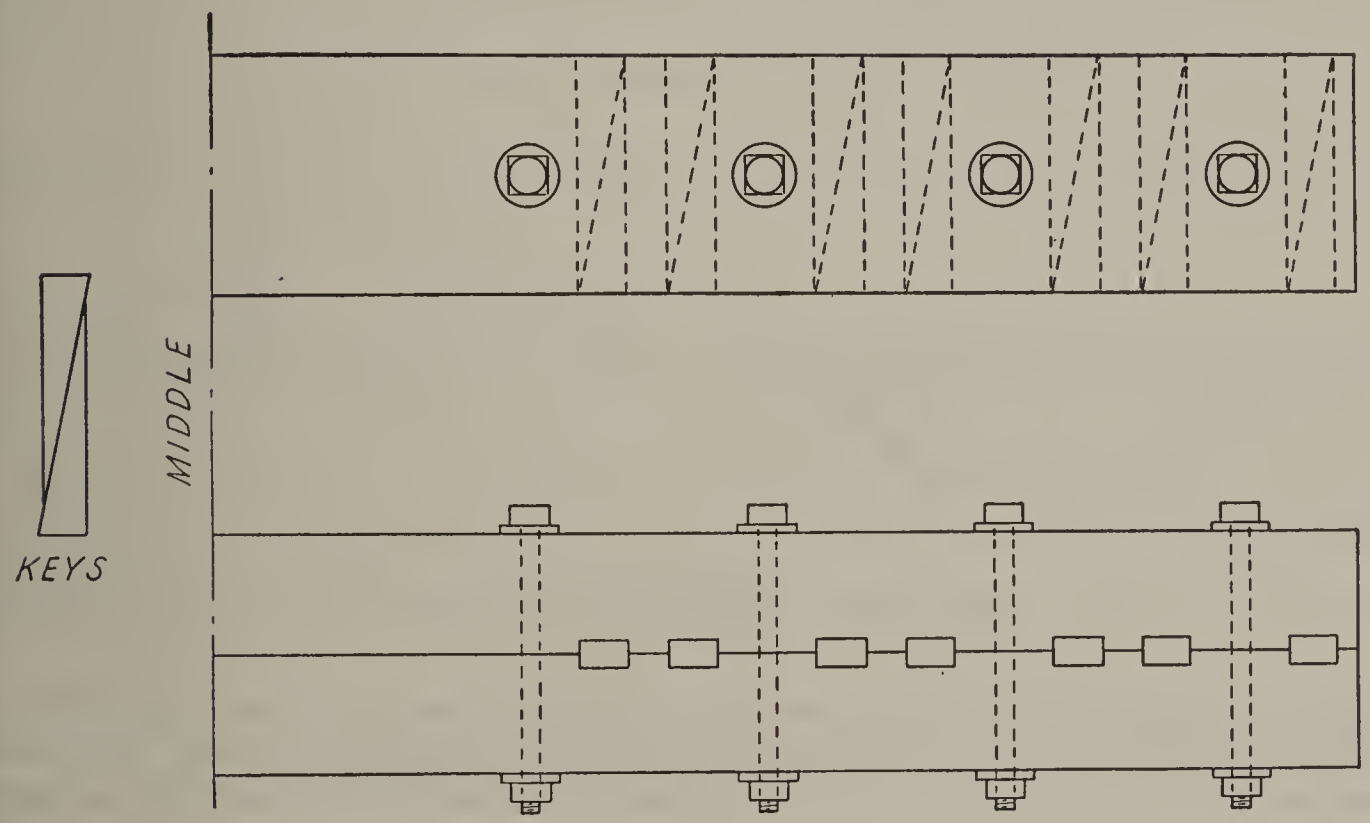


FIGURE 34.—A keyed compound beam in which the shear between adjacent timbers is taken by wood or metal keys.

The keys are sometimes tapered like wedges so that a driving fit may be obtained with pairs, but they are also made of flat plates or blocks without taper. Modern connectors of the toothed plate, toothed ring, or split ring type (p. 136) are especially suitable for keys of compound beams.

Well-seasoned timber should be used in the construction of keyed beams and great care exercised in framing.

TRUSSED BEAMS

Trussed beams can be economically used for long spans and large loads when head room permits. In the simplest form (fig. 35, *A*) the wooden beam is supported at the center by a single wooden strut or kingpost which in turn is supported by metal tie rods passing up to a thick steel plate at each end of the beam. To avoid secondary stresses the center lines of beam, rod, and end support should intersect in a point. If the available head room is above the beam the trussed type illustrated in figure 35, *B* may be used.

For the greater spans, or where head room is small or where loads are concentrated at two intermediate points queen trusses (fig. 35, *C* and *D*) are preferable to king trusses.

Sometimes two tie rods are used with a single beam, one being placed on each side. Also two beams may have a single rod between them or three beams may have two rods between them.

It is desirable to give the assembly as much depth as conditions permit in order to reduce the stresses. Greater stability is obtained with beams continuous for the full span than with beams jointed over the struts.

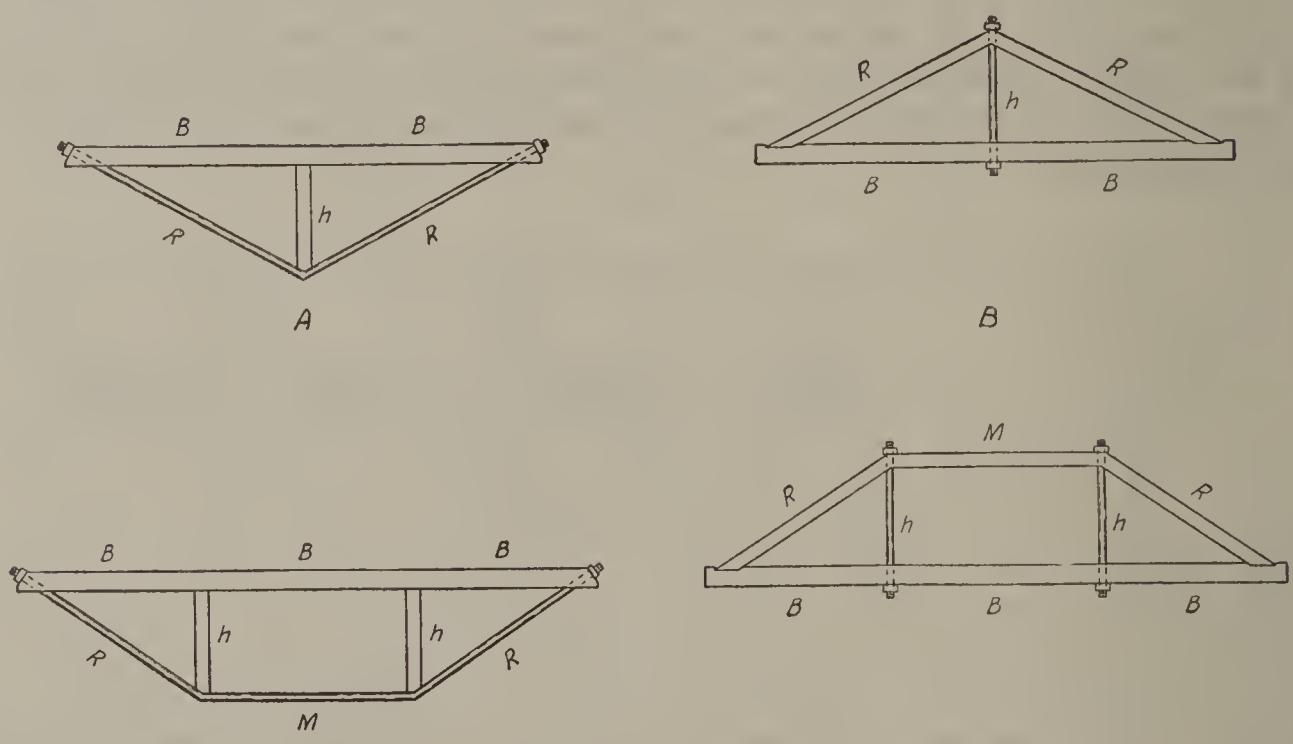


FIGURE 35.—*A* and *B*, King types of trussed beams; *C* and *D*, queen types of trussed beams.

For a single strut truss with a beam continuous for the whole span and with the triangulation below the beam (fig. 35, *A*), the stresses in the members for a uniformly distributed load W would be:

Tension in rod equals 0.312 $W \times \frac{R}{h}$ pounds; compression in strut equals 0.625 W pounds; direct compression in beam equals 0.312 $W \times \frac{B}{h}$ pounds; extreme fiber stress in beam due to bending only equals $0.375 \frac{WB}{bd^2}$ pounds per square inch where b is the breadth and d is the depth. If the beam has a joint over the strut these values become: Tension in rod equals 0.25 $W \times \frac{R}{h}$ pounds; compression in strut equals 0.5 W pounds; compression in beam equals 0.25 $W \times \frac{B}{h}$ pounds; extreme fiber stress in beam due to bending only equals $0.375 \frac{WB}{bd^2}$ pounds per square inch. In the foregoing formulas a single rod is assumed. Precautions to be observed are: The direct compression stress in the beam should be added to the flexural stress induced by the load acting upon the beam; sufficient area in the rod

should be provided on the basis of its area at the root of the thread; ample side-grain area should be provided where the strut bears against the bottom of the beam; and the bearing at the ends of the beam under the plates, which take the thrust of the rods, should be calculated by the formula (p. 57) for bearing at an angle to the grain.

For a king truss with the triangulation above a continuous beam (fig. 35, *B*) the stresses will be of the same intensity as given above for the same type of beam with the triangulation below, but the character of the direct stresses will be reversed.

For a double-strut truss with three equal panels with struts below the beam (fig. 35, *C*) and with the beam continuous, the stresses for a uniformly distributed load W would be approximately: Tension in rod R equals $\frac{W}{3}\times\frac{R}{h}$ pounds; compression in strut equals $\frac{W}{3}$ pounds; direct compression in beam equals $\frac{W}{3}\times\frac{B}{h}$ pounds; tension in rod M equals $\frac{W}{3}\times\frac{B}{h}$; extreme fiber stress in beam due to bending only equals $0.2\,\frac{WB}{bd^2}$ pounds per square inch.

For a double-strut truss with vertical tie rods above the beam (fig. 35, *D*) the stresses will be of the same intensity as just given, but the character of the direct stresses will be reversed.

Stresses for other conditions of loading are readily determined analytically or graphically and appear in numerous handbooks and textbooks.

LATERAL BUCKLING OF BEAMS

A beam much deeper than it is wide may fail through buckling laterally and twisting at loads much less than those calculated by means of the usual beam formula,

$$M=\frac{sI}{c}$$

in which M represents the bending moment; s, the unit stress due to the bending moment upon the fiber most remote from the neutral axis; I, the moment of inertia of the cross section about the neutral axis; and c, the normal distance from the neutral axis to the outermost fiber. For each condition of end fixity and loading, there is a critical lateral buckling load for a deep beam that in many respects is similar to the critical load of a column. Mathematical analysis of the problem of such instability has led to formulas for calculating the critical loads for various fixity and loading conditions (Trayer and March).

Following are the formulas covering 12 different conditions of loading and end fixity for solid rectangular wooden beams. It is not to be expected that practical loading and fixity conditions will exactly correspond to any of the theoretical conditions stated. However, in some instances the actual condition may agree fairly well with one of the theoretical conditions, and in other instances one or more of the theoretical formulas may furnish an indication of the performance to be expected under some practical condition. In these

formulas M represents the critical buckling moment; P, the critical concentrated buckling load; W, the critical uniformly distributed buckling load; E, the modulus of elasticity along the grain; I_2, the moment of inertia about the principal vertical axis (not to be confused with the moment of inertia about the neutral axis); G, the modulus of rigidity in torsion; L, the span; and K, the torsion constant of the section.

To illustrate what is meant by I_2 and K, consider a rectangular beam b wide and d deep, for which

$$\left(I_2=\frac{db^3}{12}\right)$$

and K is expressed as

$$K=\beta db^3$$

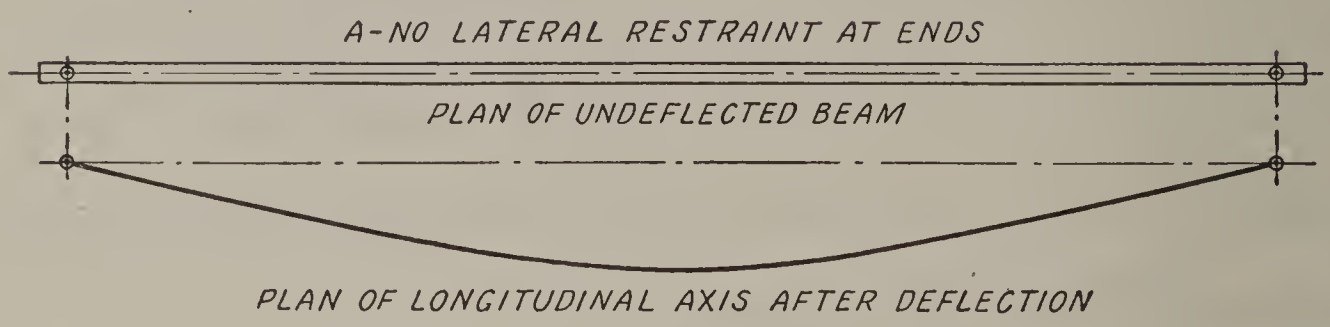


FIGURE 36.—Lateral deflection of longitudinal axis in beams for three common conditions of restraint.

in which β is a constant depending upon the ratio of d to b. Table 38 gives the values of β for various values of this ratio. The value of K for sections other than rectangular is not so simply expressed.

In all instances the ends of the beam are assumed to be vertical. An end not restrained, in the terminology used, is held vertical but

is not otherwise restrained. and an end restrained is both held vertical and clamped against lateral rotation. Figure 36 shows the type of lateral deflection of the longitudinal axis for three common conditions of restraint.

TABLE 38.—*The factor β for calculating the torsional rigidity of rectangular prisms*

Ratio of sides. d/b	β	Ratio of sides. d/b	β	Ratio of sides. d/b	β	Ratio of sides. d/b	β
1	0.14058	1.45	0.19145	2.50	0.24935	8	0.30707
1.05	.14744	1.50	.19576	2.75	.25866	9	.30999
1.10	.15398	1.60	.20374	3	.26832	10	.31232
1.15	.16021	1.70	.21063	3.50	.27331	20	.32283
1.20	.16612	1.75	.21428	4	.28051	50	.32913
1.25	.17173	1.80	.21743	4.50	.28665	100	.33123
1.30	.17707	1.90	.22332	5	.29135	∞	.33333
1.35	.18211	2	.22868	6	.29832		
1.40	.18690	2.25	.24012	7	.30332		

CASE 1. A thin, deep, rectangular beam under uniform bending moment M, with its ends not restrained.

$$M=\frac{\pi\sqrt{EI_2GK}}{L}$$

CASE 2. The same as case 1 except that the ends are restrained.

$$M=\frac{2\pi\sqrt{EI_2GK}}{L}$$

CASE 3. A thin, deep, rectangular cantilever with a concentrated load P at the end.

$$P=\frac{4\sqrt{EI_2GK}}{L^2}$$

CASE 4. A thin, deep, rectangular cantilever with a uniformly distributed load W.

$$W=\frac{12.9\sqrt{EI_2GK}}{L^2}$$

CASE 5. A thin, deep, rectangular beam supported at the ends and carrying a concentrated load P at the middle with its ends not restrained.

$$P=\frac{16.9\sqrt{EI_2GK}}{L^2}$$

CASE 6. The same as case 5 except that the ends are restrained.

$$P=\frac{25.9\sqrt{EI_2GK}}{L^2}$$

CASE 7. A thin, deep, rectangular beam supported at its ends and carrying a uniformly distributed load W, with its ends not restrained.

$$W=\frac{28.3\sqrt{EI_2GK}}{L^2}$$

CASE 8. The same as case 7 except that the ends are restrained.

$$W=\frac{43.3\sqrt{EI_2GK}}{L^2}$$

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CASE 9. A thin, deep, rectangular beam subjected to a constant bending moment M and an axial thrust P', with its ends not restrained.

$$M=\frac{\pi\sqrt{EI_2GK}}{L}\sqrt{1-\frac{P'L^2}{\pi^2EI_2}}$$

CASE 10. The same as case 9 except that the ends are restrained.

$$M=\frac{2\pi\sqrt{EI_2GK}}{L}\sqrt{1-\frac{P'L^2}{4\pi^2EI_2}}$$

CASE 11. A thin, deep, rectangular beam supported at its ends and carrying both a uniformly distributed load W and a concentrated load P at the middle, with its ends not restrained.

$$\frac{PL^2}{16.9}+\frac{WL^2}{28.3}=\sqrt{EI_2GK}$$

CASE 12. A thin, deep, rectangular beam supported at its ends and carrying a concentrated load P at its middle, with lateral support, as by tie rods or bridging, at the middle, and the ends not restrained. Such a beam buckles laterally in two half waves (fig. 36).

$$P=\frac{44.5\sqrt{EI_2GK}}{L^2}$$

The calculation of a critical load that produces a fiber stress beyond the proportional limit is possible by means of the preceding formulas if the modulus for inelastic deformation is known. Although this modulus is a variable beyond the proportional limit, it may be obtained from a stress-strain diagram (Trayer and March).

The formulas for I-beams are more complicated than those for beams of rectangular section, and the values of the torsion constant K for such sections cannot be simply expressed. Since at the present time the use of wood I-beams is confined chiefly to special constructions, such as aircraft (Trayer and March), these formulas are not given here.

WOOD COLUMNS

SOLID COLUMNS

COLUMNS OF RECTANGULAR SECTION

Solid wood columns fall into three general classes characterized by the type of failure. When the length does not exceed 11 times the least dimension, failure is by crushing. At lengths between 11 and K times the least dimension, failure is a combination of crushing and lateral buckling (Newlin and Gahagan). The significance of K is explained in the following paragraphs. Beyond this range, wood columns generally fail by lateral deflection or buckling, behaving essentially as Euler columns.

For the first class, which may be called the short column or post class, the same unit stress is recommended for all lengths having a ratio of unsupported length to least dimension of 11 or less. Since most wooden columns are rectangular or square in section, the slenderness ratio is commonly expressed as $\frac{L}{d}$, in which L is the unsupported length in inches and d the least side in inches. The more

general form is $\frac{L}{r}$, in which the term r denotes the radius of gyration of the cross section. For short columns or posts, that is, columns with $\frac{L}{d}$ ratios of 11 or less,

$$\frac{P}{A}=S$$

in which $\frac{P}{A}$ represents the working stress for the column and S represents the safe unit compressive stress parallel to the grain. Values of S are given on page 103.

For columns of the intermediate class, that is, with $\frac{L}{d}$ ratios between 11 and K, the following formula (Newlin and Gahagan) is recommended:

$$\frac{P}{A}=S\left[1-\frac{1}{3}\left(\frac{L}{Kd}\right)^4\right]$$

in which $\frac{P}{A}$ and S have the same meaning as before and K is a constant depending upon S and the modulus of elasticity. The value K is the minimum value of $\frac{L}{d}$ at which the column will behave as an Euler column. This value is obtained when

$$\frac{P}{A}=\frac{2S}{3}$$

Solving for K or $\frac{L}{d}$ when $\frac{P}{A}=\frac{2S}{3}$,

$$K=\frac{\pi}{2}\sqrt{\frac{3E}{6S}}$$

Introducing a factor of safety of 3 for E,

$$K=\frac{\pi}{2}\sqrt{\frac{E}{6S}}=0.64\sqrt{\frac{E}{S}}$$

in which E = the modulus of elasticity. Values of E are given on page 103.

For columns within the Euler column class, that is, for $\frac{L}{d}$ ratios equal to K or greater, the following formula based on the Euler formula for long columns with a factor of safety of three is recommended:

$$\frac{P}{A}=\frac{0.274E}{\left(\frac{L}{d}\right)^2}$$

The values (p. 103) to be substituted for S in the formulas for short and for intermediate columns have a safety factor of approximately four.

Examples: Calculate the safe load for a 10 by 10 inch column if S and E are 1,300 and 1,600,000 pounds per square inch, respectively, and the column is (1) 8 feet long; (2) 14 feet long; (3) 20 feet long. The actual dimensions of the 10 by 10 inch timber are 9½

by 9½ inches. For a length of 8 feet the column is within the short-column class and S is multiplied by the area. The safe load is 9½ by 9½ by 1,300 = 117,300 pounds.

In calculating the safe load for the 14-foot column K must first be determined and then the $\frac{L}{d}$, which if less than K places the column in the intermediate length class. Since E is 1,600,000 pounds per square inch

$$K=0.64\sqrt{\frac{1{,}600{,}000}{1{,}300}}=22.4$$

For a length of 14 feet the $\frac{L}{d}$ ratio is

$$\frac{14\times12}{9.5}=17.7$$

which is between 11 and 22.4 and the column is, therefore, in the intermediate class and

$$\frac{P}{A}=1{,}300\left[1-\frac{1}{3}\left(\frac{17.7}{22.4}\right)^4\right]$$

$=1{,}130$ pounds per square inch, and the safe load is 9½ by 9½ by 1,130=102,000 pounds. With a 20-foot length $\frac{L}{d}=25.3$, which is greater than K, and the column falls in the Euler class and

$$\frac{P}{A}=\frac{0.274\times1{,}600{,}000}{(25.3)^2}$$

$=685$ pounds per square inch, and the safe load is 9½ by 9½ by 685=61,800 pounds.

Columns of Circular Section

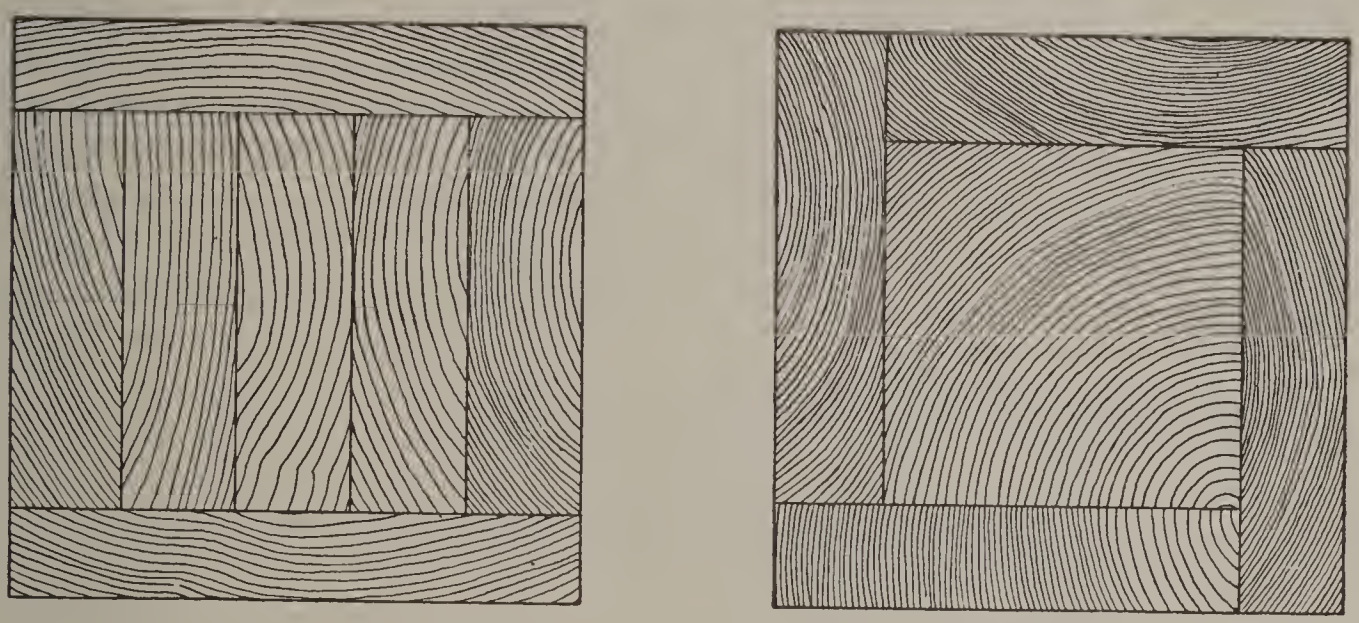
Round and square wood members of the same cross-sectional area will carry the same loads in both bending and compression and will have approximately the same stiffness. To compute the required size of a round column, design first for a square column and then use a round column of a diameter that will give an area equivalent to the area of the square. If the column is tapered, the diameter for use as d and for computing A in the Euler formula should be taken at one-third of the length from the smaller end. This will give a diameter of a round column necessary to prevent failure from buckling. The unit compressive stress at the small end of the column that will result from the calculated load should also be computed since it must not exceed the allowable stress for a short column.

LAMINATED COLUMNS

Laminated columns here referred to are those built up of several pieces spiked, bolted, or fastened together with modern connectors. No arrangement of laminae or kind of mechanical fastenings will make a laminated column fully equal in strength to a solid column of comparable material and like dimensions (Scholten). There are certain arrangements of the individual pieces, however, that are more effective than others. In one arrangement several pieces are spiked

face to face and have their edges tied together with cover plates (fig. 37, *A*); in another four planks are boxed around a solid core (fig. 37, *B*). The percentage of solid-column strength that may be expected at various $\frac{L}{d}$ ratios for these two types of built-up columns are given in the following tabulatiton. The least dimension d is an overall dimension.

$\frac{L}{d}$ ratios:	*Percent of solid column strength*	$\frac{L}{d}$ ratios:	*Percent of solid column strength*
6	82	18	65
10	77	22	74
14	71	26	82



A B

FIGURE 37.—Two types of built-up columns: *A*, Edges tied together with cover plates; *B*, boxed solid core.

It is apparent from the tabulation that there is a critical slenderness ratio at which the built-up column is least efficient as compared with the solid column. For $\frac{L}{d}$ ratios of 10 or more the percentages apply both to built-up columns in which the individual pieces are full length and to those in which butt-jointed pieces are used. In short posts, where the stress is primarily compression, pieces butted end to end fail at 75 to 80 percent of the crushing strength of full-length pieces. This is due to the embedding that occurs at the ends which are butt-jointed.

WRINKLING AND TWISTING OF COMPRESSION MEMBERS HAVING THIN OUTSTANDING FLANGES

When a compression member fails, it ordinarily does so through crushing if it is short, and through flexure if it is long. In addition, however, a column having thin, outstanding parts (fig. 38) may fail at a load much lower than that indicated by the usual column theory (Trayer and March). Such a member may fail through wrinkling of the outstanding parts or through twisting of the entire member about its longitudinal axis. Each phenomenon is governed by individual laws, and both phenomena differ from the usual column behavior. Failure of any kind in crushing, flexure, wrinkling, or twisting, will come from that particular stress or combination of stresses to which the resistance of the member is the least.

The critical wrinkling and twisting loads can be calculated from the following formulas:

WRINKLING

When an outstanding flange under a compressive load projects from a member that is high in torsional stiffness, the flange may wrinkle into several waves if the ratio of its width to its thickness is great. The critical stress p is given by the formula

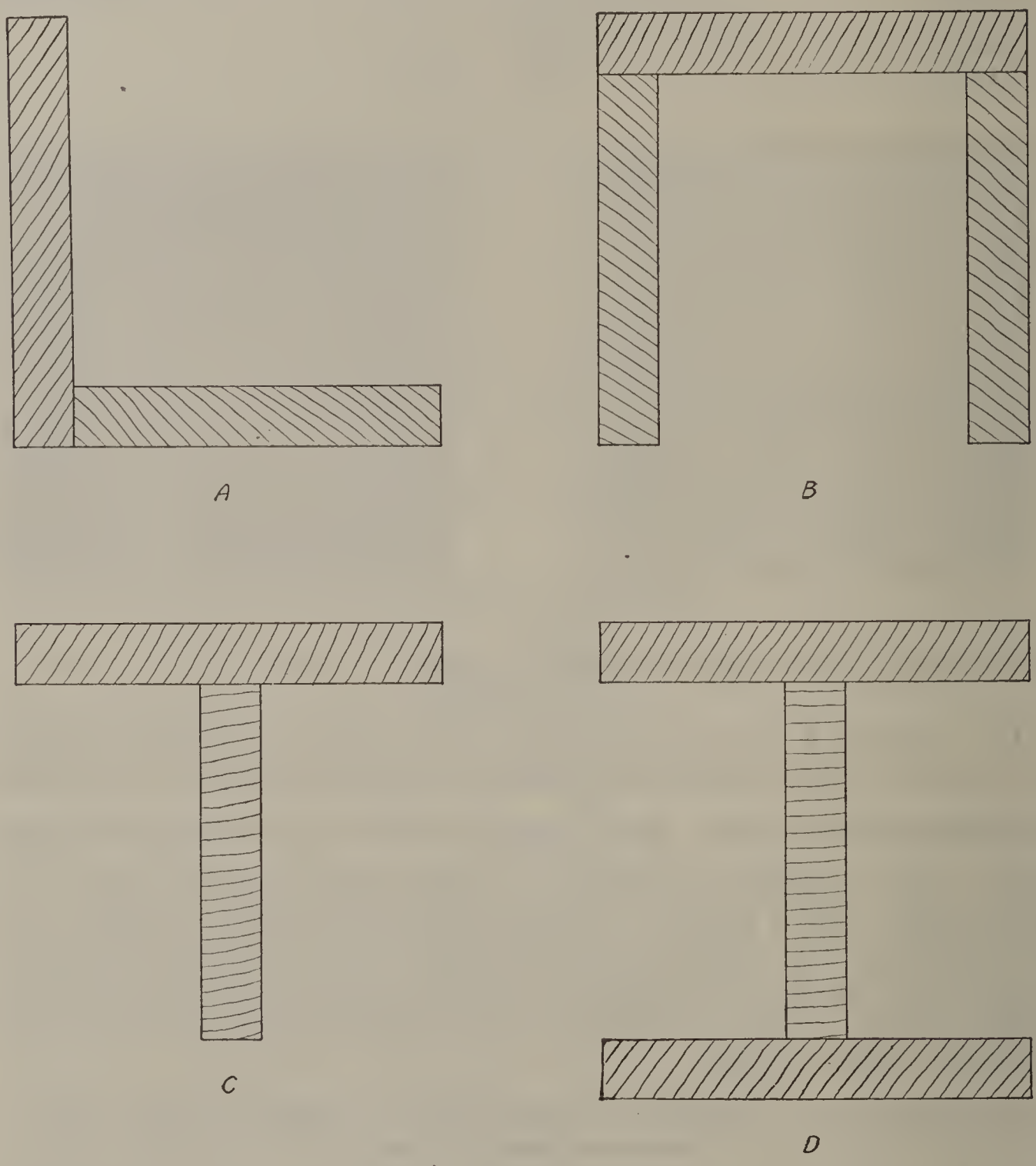


FIGURE 38.—Typical cross sections of compression members that are likely to fail through elastic instability: *A*, L-section; *B*, U-section; *C*, T-section; *D*, I-section.

$$p = kE\frac{h^2}{b^2}$$

in which E is the modulus of elasticity along the grain, h the thickness of the flange, b its width, and k a coefficient depending upon the ratio of the length a of flange to its width b.

The coefficient k may be calculated if the properties of the material are known, but the analysis assumes perfect fixity at the base of the flange, a condition probably never realized in actual practice. Consequently, the coefficient determined experimentally for wood does not agree with the calculated value. Incidentally, the same is

true for steel. In both instances, the actual coefficient is smaller than the theoretical one.

The minimum coefficient was determined experimentally for Sitka spruce and was found to be 0.07. The minimum critical wrinkling stress is then given by the formula

$$p=0.07E\frac{h^2}{b^2}$$

It is very likely that this same coefficient may be applied to other species without appreciable error.

The coefficient k in the general expression is a minimum when the ratio of the length of flange a to the critical half wave length c is an integral number. If the outstanding flange is short and a/c is not an integer, the critical stress may be considerably greater than that given by the formula because the flange cannot wrinkle into ideal half wave lengths. If the length is great, that is, if a/c is greater than 2 or 3, and the ratio a/c is not an integer, however, the critical stress will be only slightly higher than that given by the formula, since the flange can then wrinkle into half wave lengths very close to the ideal.

The principal purpose in calculating the wrinkling stress is to make sure that it is greater than the stress associated with the primary failure; wrinkling is a secondary failure. Each outstanding part of a member should be so proportioned that it will not buckle individually at a stress less than that expected of the member as a whole.

Twisting

If one or more relatively wide and thin parts project from a compression member that does not have great torsional stiffness, the outstanding part or parts may form into single half waves and twist the member about its own longitudinal axis. This is likely to occur with sections like A of figure 38. The outstanding parts of such a member act essentially as plates simply supported along one edge and free along the opposite edge. The critical stress for spruce plates under compression and so supported is given by

$$p=0.044\,E\frac{h^2}{b^2}.$$

It is probable that the same coefficient (0.044) may be used for other species without appreciable error.

Sections B, C, and D, in figure 38, would be likely to twist if their torsional rigidity were not great. If generous fillets were used in any of these sections the preceding coefficient would increase. Actually, the rigidity of the member may be such that the failure would occur at a critical stress between the minimum twisting stress given by the formula

$$p=0.044\,E\frac{h^2}{b^2}$$

and the minimum wrinkling stress given by the formula

$$p=0.07\,E\frac{h^2}{b^2}.$$

It is virtually impossible to calculate accurately the coefficients for intermediate conditions. A simple scheme is to calculate the twisting

stress for such sections as L, H, and U on the assumption that no fillets are present, by using the coefficient 0.044. This stress may then be increased by multiplying it by the ratio of the torsional rigidity of the actual section to that of the assumed section. This rule applies until the limiting critical stress corresponding to the coefficient 0.07 is reached.

As with wrinkling, the chief concern in calculating the twisting stress is assurance that it is greater than the stress expected of the member as a whole.

WOOD ARCHES

Since about 1900 there have been developed in Europe curved wooden members consisting of a number of laminations bent to the desired curvature and glued with waterproof glue. This construction is used for roof arches of spans as great as 100 feet and for building members that are continous from foundation to roof peak, as well as for centering for stone arches and erection scaffolding for steel structures. This type of construction seemingly has much merit and offers a promising field for development, particularly in connection with roof construction. Gluing enables the laminations to act together much more efficiently than is possible with nails, bolts, or other mechanical attachments.

Unless the curvature is very moderate, bending of laminations to the desired shape induces in them initial stresses of considerable magnitude. Preliminary tests have shown, however, that even when the curvature is as sharp as can be accomplished without breakage of the individual laminations, the glued member has about 75 percent as great strength as a similar assembly glued together but not bent. For moderate curvatures, this ratio is higher; and with a radius of curvature some 150 or more times as great as the thickness of the laminae, the strength and stiffness ratios as found from tests have been 90 percent or greater.

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GLUED WOOD CONSTRUCTION

Gluing is used extensively in the construction of wood parts of unusual properties, dimensions, and form and in fastening together parts of built-up assemblies. The efficiency of the glued joints depends upon (1) the kind of wood and its preparation for use, (2) the kind and quality of glue and its preparation for use, (3) the details of gluing, (4) the types of joints, (5) the conditioning of the joints, and (6) the protection given in service (Truax, Dept. Bull. 1500).[30]

GLUING PROPERTIES OF DIFFERENT WOODS

Table 39 gives the gluing properties of the most important woods that are glued. The classification is based on the average strength of side-grain joints of approximately average density wood of each species, glued with animal, casein, and vegetable glues. A species is considered to be glued satisfactorily when the strength of the joint obtained is approximately equal to the strength of the wood (Truax, Dept. Bull. 1500 and Tech. Bull. 205).

The ease or difficulty with which satisfactory joints are made is dependent on the density of the wood, the structure of the wood, the presence of extractives or infiltrated materials in the wood, and the kind of glue. In general, heavy woods are more difficult to glue than lightweight woods, hardwoods more difficult than softwoods, and heartwood more difficult than sapwood. A few woods, notably basswood, hickory, the gums, and the heartwood of cypress and of eastern red cedar vary considerably in their gluing characteristics with the different adhesives (Truax, Dept. Bull. 1500).

TABLE 39.—*Classification of various woods according to gluing properties*

Group 1, woods that glue easily with different glues under a wide range of gluing conditions; group 2, woods that glue satisfactorily with different glues and with moderate care in the gluing operation; group 3, woods that glue satisfactorily provided carefully controlled gluing conditions are used; group 4, woods that require special treatment before gluing to obtain the best results]

Species	Heartwood	Sapwood	Species	Heartwood	Sapwood
	Group	*Group*		*Group*	*Group*
Alder, red	2	2	Gum, tupelo	[1] 4	3
Ash, commercial white	3	3	Hemlock, western	1	1
Aspen	1	1	Hickory, pecan	2	2
Basswood	[1] 2	[1] 2	Hickory, true	[1] 4	[1] 4
Beech	4	3	Larch, western	2	2
Birch, sweet and yellow	4	3	Magnolia	3	3
Butternut	2	2	Mahogany	2	------
Cedar, Alaska	2	2	Maple, red and sugar	3	3
Cedar, eastern red	[1] 2	2	Oak, commercial red	3	3
Cedar, western red	1	1	Oak, commercial white	3	3
Cherry, black	3	3	Persimmon	------	3
Chestnut	1	1	Pine, northern white	1	1
Cottonwood	2	2	Pine, ponderosa	2	1
Cypress, southern	[1] 2	1	Pine, southern yellow	2	2
Douglas fir	2	2	Poplar, yellow	2	2
Elm, American	3	3	Redwood	1	1
Elm, rock	3	3	Spruce	1	1
Fir, commercial white	1	1	Sycamore	3	3
Gum, black	[1] 4	3	Walnut, black	3	3
Gum, red	4	3			

[1] Gluing properties vary considerably with different glues.

[30] For further information, the references at the end of this section should be consulted.

GLUES USED IN WOODWORKING

Table 40 describes briefly the characteristics, properties, preparation, and uses of the three types of glue most commonly used in making joints in wood (American Society of Mechanical Engineers). Animal glues have long been used extensively in woodworking; starch glues have come into general use, especially for veneering, during the past 25 to 30 years; and vegetable protein and casein glues, still more recent in development, have found extensive use for gluing lumber and veneer into products for which water resistance is desired.

Other classes of glues, most of which are quite different from the commonly used glues in characteristics and properties, are used in minor quantities in woodworking, and some of them may eventually come into more general use (American Society of Mechanical Engineers, and Truax, Dept. Bull. 1500). Table 40 gives a brief description of some of the glues in this classification.

TABLE 40.—*Characteristics and properties of the most commonly used woodworking glues*

Class	Grade, form and testing	Properties	Preparation and application	Uses
Animal	Many grades sold in dry form; quality most accurately determined by test on solutions of the glue (U. S. Federal Specifications Board).	High to low dry strength; low moisture resistance and durability under damp conditions; set quickly; stain wood not at all or very slightly; moderate dulling effect on tools.	Mixed with water, soaked, and melted; solution kept warm during application; conveniently applied by hand or machine spreaders; pressed cold.	Used extensively in gluing veneer; furniture, cabinet, and millwork.
Casein and vegetable protein.	Several brands sold in dry powder form; may also be prepared from raw materials by user; quality judged chiefly by tests on wood joints.	High to low dry strength; high to low moisture resistance and moderately durable under damp conditions; set quickly; stain some woods badly; pronounced dulling effect on tools.	Mixed with cold water and used cold; pressed cold.	Used extensively in gluing lumber and veneer; millwork, plywood, auto bodies, and aircraft.
Starch	Different grades sold in dry form; quality determined chiefly from joint tests.	High to low dry strength; low in moisture resisance and durability under damp conditions; quick to slow rate of settling; stain some woods slightly to moderately; moderate dulling effect on tools.	Mixed with water usually with heat; applied cold with machine spreaders; pressed cold.	Used extensively in gluing veneer and to some extent in gluing lumber, furniture, and plywood.

BLOOD ALBUMIN

Glues made from a base of blood albumin have been used for special purposes for many years, but their use has not become extensive in the United States. They are mixed from the various ingredients at the time of use and are applied cold by hand or with mechanical spreaders. Most of them require hot pressing, and they are quick setting. They are high in water resistance and durability under damp conditions. They stain wood only slightly, if at all, though their dark color may show through thin veneer. The necessity for hot pressing is the principal limitation to their extensive use.

LIQUID GLUES

Glues in liquid form, made from fish and animal products, are sold in many brands, ready for application. Their principal use in wood-

working is for small jobs and repair work. They are quite variable in quality, though all are low in water resistance and durability under damp conditions. The better brands are moderate in dry strength and fairly quick setting. They are applied cold, usually by hand, and are pressed cold. They stain wood only slightly, if at all.

SYNTHETIC RESINS

Adhesives made from phenolic and other synthetic resins are comparatively new in woodworking. They are made mainly in the forms of dry films and aqueous suspensions although they may occasionally be used as dry powders or nonaqueous solutions. Such adhesives usually require the application of heat; they set quickly. They have good dry strength and are high in water resistance and durability under damp conditions. They stain wood very slightly, if at all. Rapid developments occurring in this class of adhesives may result in improvements and economies that will extend their application and use.

MISCELLANEOUS ADHESIVES

Cellulose cements and rubber compounds, usually sold in liquid form ready to apply to wood, have had a limited application as woodworking glues. Cellulose cements are pressed cold whereas most rubber compounds require heat. Both classes of materials produce water-resistant joints. Their high cost is a present practical limitation to extensive use.

DRYING AND MOISTURE CONDITIONING WOOD FOR GLUING

The moisture content of wood at the time of gluing has much to do with the final strength of joints, development of checks in the wood, and warping of the glued members. Satisfactory adhesion of glue to wood is obtained at any moisture content of the wood up to 15 percent and even higher with water-resistant glues. Large changes in the moisture content of the wood after gluing, however, develop stresses that may seriously weaken both the wood and the joints.

The most satisfactory moisture content of wood at the time of gluing is that which, when increased by the moisture of the glue, approximately equals the average moisture content that the glued member will have in service. In gluing thick pieces this relation can be attained, but in gluing veneer or other thin pieces the moisture added by the glue frequently exceeds the moisture content of the wood in service (Truax, Dept. Bull. 1500). Under the latter conditions the wood cannot be dried enough before gluing to avoid redrying of the glued products afterward. The amount of moisture added to wood in gluing varies from less than 1 percent in lumber to 45 percent or more in thin plywood. The thickness of the wood, the number of plies, the density of the wood, the glue mixture, and the quantity of glue spread all affect the increase in moisture content of the wood.

In general practice adjustments cannot be made for all these widely varying factors, and it is seldom that wood need be dried to a moisture content below 5 percent or higher than 12 percent. Lumber with a moisture content of 5 to 6 percent is satisfactory for gluing

into furniture, millwork, and similar uses. Lumber for outside use should generally contain 10 to 12 percent of moisture before gluing. Experience has shown that a moisture content of 5 percent in veneer at the time of gluing is satisfactory for even thin plywood and veneer in furniture, millwork, and similar products. For certain uses, such as plywood for boxes, a moisture content of the veneer of 10 to 12 percent or even higher is not only permissible but is often desirable from a manufacturing standpoint.

Lumber that has been dried to the approximate average moisture content desired for gluing may still show differences between various boards and between the center and the outside of individual pieces. Large differences in the moisture content of the pieces at the time of gluing result eventually in considerable stress on glue joints and tend to produce warping of the product. Hence, it is desirable for many purposes to condition wood to a relatively uniform moisture content after drying and before gluing. Small variations of 1 percent or less between boards of the same species and size may be disregarded since they may occur even after a long conditioning period. Lumber that is to be glued should also be free from drying defects.

MACHINING LUMBER FOR GLUING

Wood surfaces that are to be glued should be smooth and true. Machining should preferably be done just before gluing so that the surfaces do not become distorted from subsequent moisture changes. In panel constructions the thickness of each lamination or ply should be uniform, that is, it should not be thinner in one part than in another. A small variation in thickness in each piece may cause a total difference of serious proportions when a number of similar pieces are piled in the same order as they come from the surfacer. Machine marks, chipped or loosened grain, and other surface irregularities are objectionable.

Surfaces made by a saw are usually rougher than those made by planers, jointers, and other machines equipped with cutter heads, but recent perfection of saws for this purpose has made it possible to glue sawed joints more extensively and thereby to effect a saving of labor and material. Joints of approximately equal strength may be made between two planed or smoothly sawed surfaces that are equally true. In cabinet work and other constructions where joints are exposed to view, the sawed joint is not entirely satisfactory because it is usually more conspicuous than the planed joint.

Intentional roughening of wood surfaces by tooth planing, scratching, or sanding with coarse sandpaper is practiced by some operators in the belief that it affords better surfaces for gluing. However, tests of joints made under good gluing practice show no benefit from roughening the surfaces.

CUTTING VENEER

Veneer for gluing is cut by sawing, slicing, or rotary processes (Knight and Wulpi). Sawed veneer is produced in long narrow strips usually from flitches selected for figure and grain. It is equally firm and strong on both sides of the sheet and either side may be glued or exposed to view with similar results.

Sliced veneer is also cut in the form of long strips by moving a flitch or block against a heavy knife. The veneer is forced abruptly away from the flitch by the knife, thus causing fine checks or breaks on the knife side. The checked side is called the open or loose side, and the other side is called the closed or tight side. The open side is likely to show defects in finishing and therefore should be the glue side whenever possible. For matching face stock where the open side of part of the sheets must be the finish side, the veneer must be well cut.

Most rotary-cut veneer is produced in large sheets by revolving a log against a knife, flat-grain veneer being peeled off in a continuous sheet. The half-round process, a modification of straight rotary cutting is used to produce highly figured veneer from stumps, burls, and other irregular parts of logs. This process consists of placing a part of a log, stump, or burl off center in a lathe and rotary cutting it into small sheets of veneer. All rotary-cut veneer has an open and a closed side. As with sliced veneer, the checked or open side should be the glue side whenever possible.

Veneer is not usually resurfaced before it is glued, and the care with which it is cut is therefore of prime importance. Provided the veneer is well cut there is no appreciable difference in the strength and other properties, except appearance, of the plywood made from veneer produced by any of the three processes. The characteristics important in selecting veneer to be glued are (1) uniformity of thickness in the same piece, (2) smoothness and flatness, (3) freedom from large checks or other defects, and (4) straightness of grain and absence of decay.

PROPER GLUING CONDITIONS

A strong joint in wood is characterized by complete contact of glue and wood surfaces over the entire joint area and a continuous film of good glue between the wood layers that is unbroken by air bubbles or by foreign particles. This result is obtained by a control of the details of the gluing operation (Douglas and Pettifor, and Truax, Dept. Bull. 1500, and Tech. Bull. 205.)

Making strong glue joints with glues applied in liquid condition depends primarily upon a proper correlation between gluing pressure and glue consistency at the moment the pressure is applied. The consistency of the glue mixture after being spread on the wood is extremely variable, depending upon such factors as the kind of glue, glue-water proportion of the mixture, quantity of glue spread, moisture content of the wood, temperature of the glue, room, and wood, the time elapsing between spreading and pressing, and the extent to which the glue-coated surfaces are exposed to the air. The functions of pressure are to squeeze the glue out into a thin continuous film between the wood layers, to force air from the joint, to bring the wood surfaces into intimate contact with the glue, and to hold them in this position during the setting of the glue. A light pressure should be used with a thin glue, a heavy pressure with a thick glue, and corresponding variations in pressure should be made with glues of intermediate consistencies.

Joints should be retained under pressure at least until they have sufficient strength to withstand the interior stresses tending to

separate the wood pieces. In cold pressing operations it is safe to assume that under favorable gluing condititons this stage will be reached in 2 to 7 hours, according to the thickness and the absorptive characteristics of the wood. A pressing period beyond the minimum is advisable as a precautionary measure when operating conditions permit. In hot-pressing operations the time required varies with the temperature of the platens, the thickness and kind of material being pressed, and the kind of glue. The variation in time in actual practice is from 2 minutes to as much as 30 minutes.

Gluing with the dry forms of adhesives requires special conditions that vary somewhat with the particular adhesive and class of product.

TYPES OF GLUE JOINTS

SIDE-GRAIN SURFACES

With most species of wood straight, plain joints between side-grain surfaces can be made substantially as strong as the wood itself in shear parallel to the grain, tension across the grain, and cleavage. The tongue-and-groove, dovetail, and other shaped joints (fig. 39) present the theoretical advantage of larger gluing surfaces than do the straight joints, but they do not give higher strengths with most woods. Furthermore, the theoretical advantage is often lost, wholly or in part, because the shaped joints are more difficult to machine than straight, plain joints so as to obtain a perfect fit of the parts. Lack of contact may make the effective holding area actually smaller on a shaped joint than on a flat surface and thus reduce rather than increase the strength. Only under circumstances where the gluing conditions are not well controlled and the joints are weak do the larger contact surfaces of well-fitted joints improve the strength. The principal advantage of the tongue-and-groove and other shaped joints is that the parts can be more quickly aligned in the clamps or press. A shallow tongue-and-groove is usually as useful in this respect as a deeper cut and is less wasteful of wood.

END-GRAIN SURFACES

It is practically impossible to make end-butt joints sufficiently strong or permanent to meet the requirements of ordinary service. With the most careful gluing possible not more than about 25 percent of the tensile strength of the wood parallel with the grain can be obtained in butt joints. In order to approximate the tensile strength of various species a scarf, serrated, or other form of joint that approaches a side-grain surface must be used. The plain scarf is perhaps the easiest to glue and entails fewer machining difficulties than the many-angle forms.

The following slopes are considered necessary to produce joints as strong in tension along the grain as the solid wood:

Species:	*Slope*
Birch, yellow	1 in 12
Gum, red	1 in 8
Mahogany	1 in 10
Poplar, yellow	1 in 8
Oak, red	1 in 15
Oak, white	1 in 15
Walnut, black	1 in 15

End-to-side-grain joints are also difficult to glue properly and, further, are subjected in service to unusually severe stresses as a result of unequal dimensional changes in the two members of the

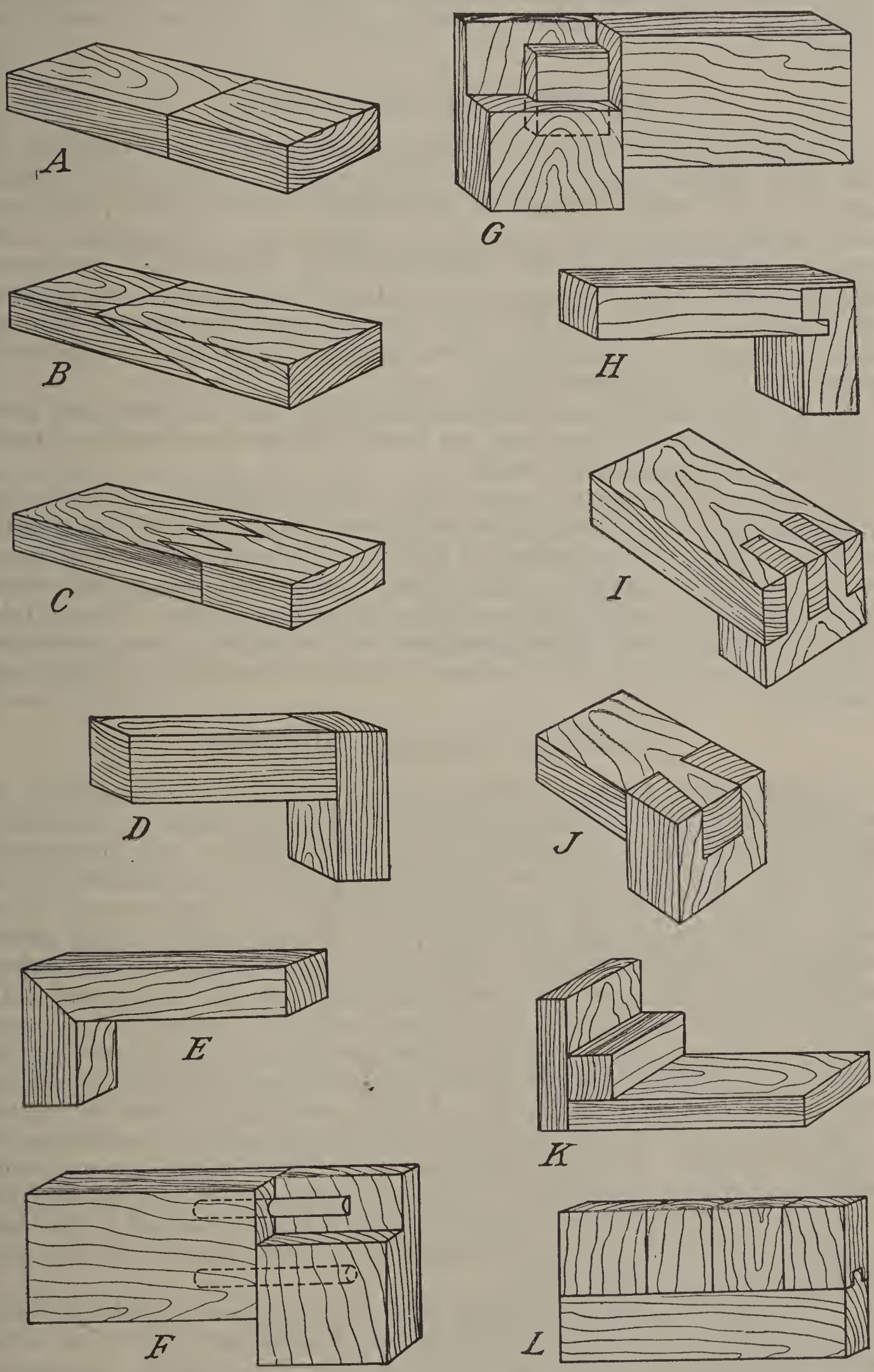


FIGURE 39.—Types of butt-joint construction: *A*, End to end; *B*, scarf; *C*, serrate or finger; *D*, end to side; *E*, miter; *F*, dowel; *G*, mortise and tenon; *H*, dado tongue and rabbet; *I*, slip or lock corner; *J*, dovetail; *K*, blocked; *L*, tongue and groove.

joint with moisture-content changes. It is, therefore, necessary to use irregular shapes of joints, dowels, tenons, or other devices to reinforce such a joint in order to bring side grain into contact with side grain or to secure larger gluing surfaces. All end-to-side-grain joints should be carefully protected against changes in moisture content.

CONDITIONING GLUED JOINTS

In gluing lumber edge to edge the wood immediately adjacent to the joint absorbs more water from the glue and therefore swells more than the other portions of the boards. If the glued pieces are surfaced before this excess moisture is dried out or distributed, more wood is removed along the joints than at intermediate portions. Subsequently, when the moisture content becomes uniform greater shrinkage occurs at the joints than elsewhere and permanent depressions are formed. Such depressions along the glue line may be very conspicuous in a finished panel.

In gluing lumber and other thick pieces face to face, the glue moisture need not be dried out but simply allowed to distribute itself uniformly throughout the wood.

In plywood, veneered panels, and other constructions made by gluing together thin layers of wood, it is advisable to dry out a part, at least, of the moisture added in gluing in order to reach an average service moisture content. The drying is most advantageously done under controlled conditions and time schedules (Truax, Dept. Bull. 1500). Drying such glued products to excessively low moisture-content values materially increases warping, opening of joints, and checking.

DURABILITY OF GLUED MEMBERS

Adequate data are not available for fixing the moisture content at or below which the different glues retain their strength permanently. However, available information indicates that in well-constructed joints any of the common woodworking glues are permanently durable under conditions where wood has 12 percent moisture content or less. Joints made with nonwater-resistant glues fail quickly when exposed to damp conditions. Even the more commonly used water-resistant glue joints, which show a strength when first saturated with water of 25 to nearly 100 percent of their dry strength, fail completely when exposed without protection for a long time to free water or to extremely high relative humidity or when alternated between wet and dry conditions. Under conditions where wood retains 20 percent or more moisture there is no positive assurance of the permanence of the more common water-resistant glued joints without special treatments. The use of a glue that has natural resistance to deterioration or the addition of toxic material to the less durable glues increases the serviceability of glued products (Brouse, and Truax, Tech. Bull. 205).

Treatments of glued members that increase their durability may be grouped into two general classes: (1) Coatings that reduce the moisture content changes in the wood and glue, and (2) impregnation with preservatives or toxic materials. Effective moisture-

excluding coatings are useful in reducing the magnitude of moisture-content changes in wood and glue and in lessening the weakening effect on the glue of the swelling stresses that occur during temporary periods of exposure to damp conditions. They are not effective in their protection against prolonged periods of exposure to damp conditions. Impregnation of glued members with preservatives reduces the deteriorating effects of prolonged exposure to damp conditions. The useful life of casein and blood-albumin water-resistant plywood may be doubled or tripled by impregnations that protect both glue and wood (Brouse), such as coal-tar creosote or a 10 percent solution of beta naphthol in a volatile solvent.

PLYWOOD AND OTHER CROSSBANDED PRODUCTS

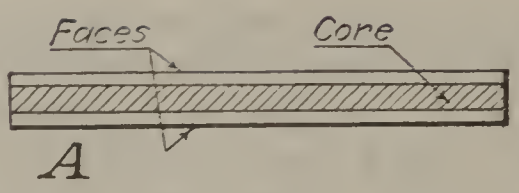
Plywood is a term generally used to designate glued wood panels that are made up of 2 or more thin layers with the grain of 1 or more at an angle, usually 90°, with the others (Bureau of Standards, Navy and War Departments). The outside plies are called faces or face and back, the center ply or plies are called the core, and intervening plies, laid at an angle to the other plies, are called the crossbands (fig. 40). The essential features of plywood are embodied in other glued constructions with many variations of details. The core may be veneer, lumber, or various combinations of veneer and lumber, the total thickness may be less than one-sixteenth of an inch or more than 3 inches, the different plies may vary as to number, thickness, and kinds of wood, and the shape of the members may also vary. The crossbands and their arrangement largely govern the properties and uses of all such constructions (Truax and Brouse).

ARRANGEMENT OF PLIES

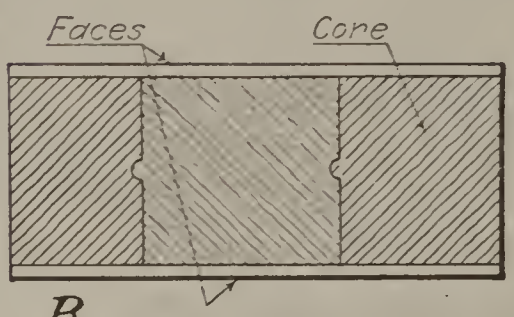
The tendency of crossbanded products to warp as the result of stresses set up from shrinking and swelling with moisture-content changes is largely eliminated by balanced construction. This construction consists of arranging the plies in pairs about the core or central ply so that for each ply there is an opposite, similar, and parallel ply. Matching the plies involves a consideration of (1) thickness, (2) kind of wood with particular reference to shrinkage and density, (3) moisture content at the time of gluing, and (4) angle or relative direction of the grain.

The use of an odd number of plies permits an arrangement that gives a substantially balanced effect; that is, when 3 plies are glued together with the grain of the outer 2 plies at right angles to the grain of the center ply, the stresses are balanced and the panel tends to remain flat with moisture content changes. With 5, 7, or other uneven number of plies the forces may also be similarly balanced. If only two plies are glued together with the grain at right angles to each other, each ply tends to distort the other when moisture content changes occur, and cupping usually results. Similar results are likely when any even number of plies are used.

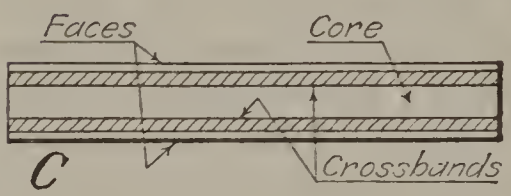
The use of balanced construction is highly important in thin panels that must remain flat. In thicker members some deviation from



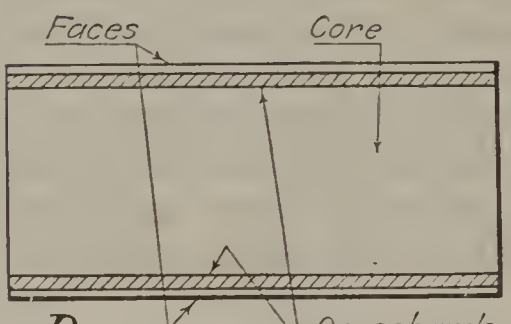
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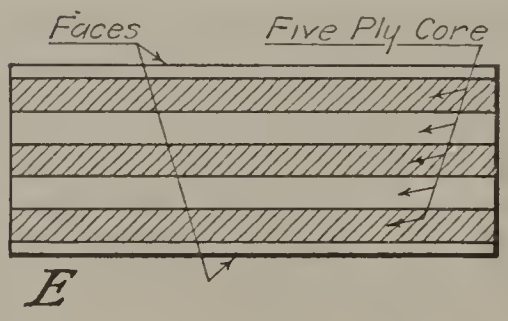
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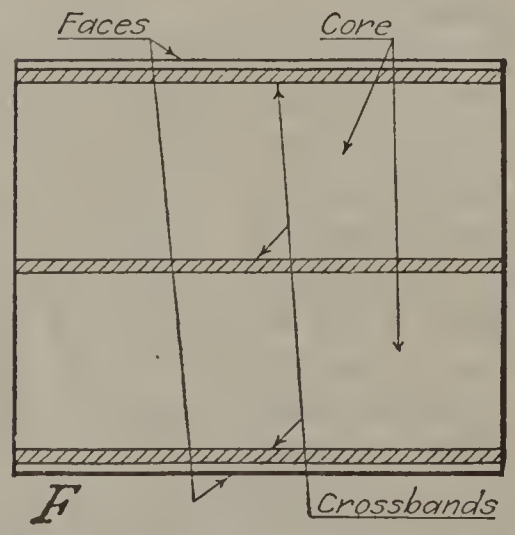
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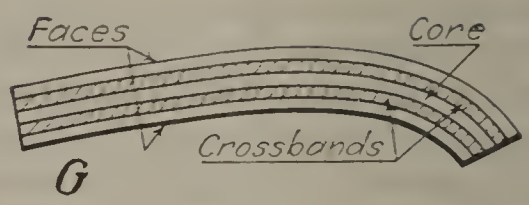
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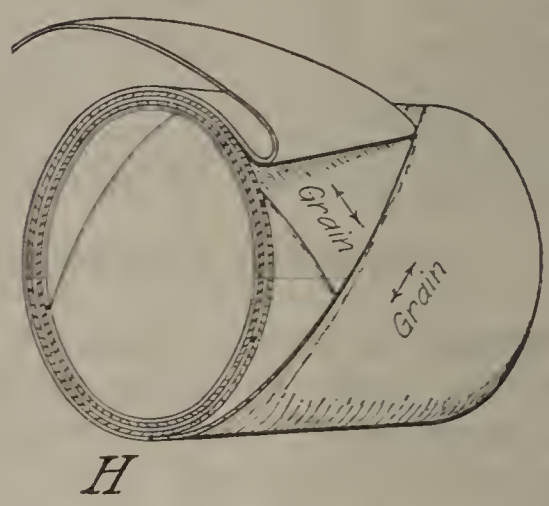
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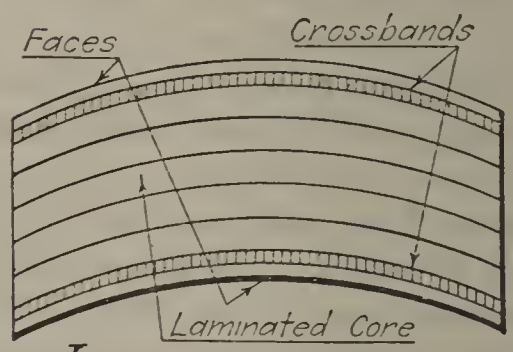
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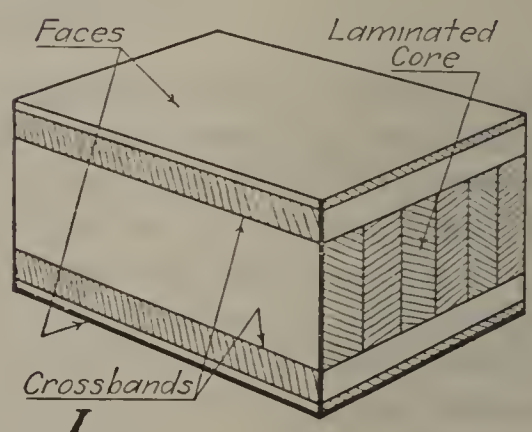
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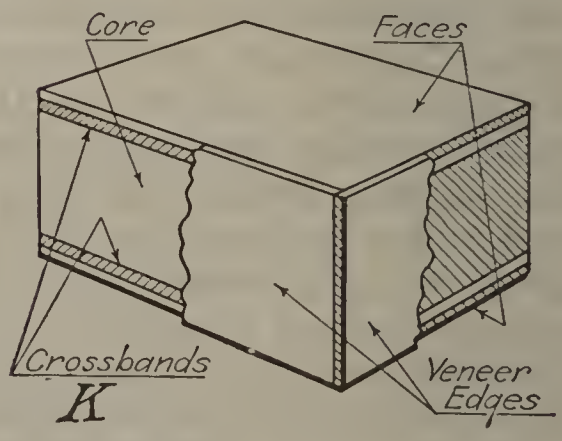
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FIGURE 40.—Types of plywood and veneered construction: *A*, 3-ply (all veneer); *B*, 3-ply (lumber core); *C*, 5-ply (all veneer); *D*, 5-ply (lumber core); *E*, 7-ply (all veneer); *F*, 7-ply (lumber core); *G*, 5-ply bent work (all veneer; *H*, 5-ply, spirally wrapped (all veneer); *I*, 9-ply bent work (laminated veneer core); *J*, 5-ply (vertically laminated veneer core); *K*, 5-ply (veneered edges and lumber core).

balanced construction is possible without serious consequences. For example, with lumber cores that are properly crossbanded the face and back plies may be quite dissimilar without any noticeable effect; whereas if the same face and back plies were used in thin three-ply panels, the warping might be very objectionable. In certain curved members the natural cupping tendency of an even number of plies may even be utilized advantageously.

Since the outer or face plies of a crossbanded construction are restrained on only one side, changes in moisture content induce relatively large stresses on the outer glue joints. The magnitude of stresses depends upon such factors as thickness of plies, density and shrinkage of the woods involved, and the amount of the moisture-content changes. In general, one-eighth inch is about the maximum thickness of face plies that can be held securely in place when dense woods are used and large moisture changes occur.

QUALITY OF PLIES

In thin plywood the quality of all the plies affects the shape and permanence of form of the panel. The various plies should be straight grained, smoothly cut, and of sound wood, that is, of uniform growth and texture.

In thick, five-ply panels the crossbands, in particular, affect the shape and form of the panel. Imperfections in the crossbands, such as marked differences in the texture of the wood or irregularities in the surface, are easily seen in the panel through thin surface veneers. Cross grain that runs sharply through the crossband veneer from one face to the other causes the panels to cup. Cross grain that runs diagonally across the face of the crossband veneer causes a twisting of the panel unless the two crossbands are laid with the grain parallel to each other. Lack of observance of this simple precaution is accountable for much warping in crossbanded construction (Truax and Brouse).

The best woods for cores of high-grade panels are those of low density and shrinkage, of slight contrast between spring wood and summer wood, and of species that are glued easily. Edge-grained are better than flat-grained cores because of the lesser shrinkage in width. In softwoods with pronounced summer wood, edge-grained cores are better than flat-grained cores for the additional reason that the hard bands of summer wood are less likely to show through thin veneer. In most species a core made of all quarter-sawed or all flat-sawed material remains more uniform in thickness with moisture-content changes than one in which these two types of material are combined. This advantage is not of great practical significance, however, where the pieces of the core are narrow and the glue joints are strong.

STRENGTH AND SHRINKAGE OF PLYWOOD

As compared with solid wood, the chief advantages of plywood are its approach to equalization of strength properties along the length and width of the panel, greater resistance to checking and splitting, and less change in dimensions with changes in moisture content (Elmendorf).

These advantages are obtained by alternating the direction of grain in the successive plies. Since the strength of wood across the grain is much lower than along the grain, equalization of strength properties in a plywood panel is approached through an increase in strength in one direction accompanied by a decrease in strength in the other direction. Thus, a piece of plywood acting as a simple beam with the direction of the grain in the face plies parallel to the direction of span is not so strong as a piece of ordinary wood with its grain parallel to the direction of span. On the other hand, plywood has much greater bending strength across the grain of the face plies than solid wood has across the grain.

The greater the number of plies for a given thickness, the more nearly equal are the strength properties along and across the panel and the greater the resistance to splitting. Furthermore, the shrinkage of plywood with five or more plies is somewhat less than that of three-ply material and more nearly equal in directions parallel and perpendicular to the face grain.

BENDING STRENGTH

The bending strength of plywood acting as a simply supported beam may be estimated by the formula

$$M = \frac{KSI}{c}$$

in which M represents the bending moment; K, a factor depending upon number of plies and direction of face grain; S, the modulus of rupture of the solid wood; I, the moment of inertia about the neutral axis of only those plies that have their grain parallel to the span; and c, the distance from the neutral axis to the outer fiber of the outermost ply having its grain parallel to the span.

For plywood of three or more plies with the grain of the face plies parallel to the length of the span, K equals 0.85.

For plywood of three plies with the grain of the face plies perpendicular to the span, K equals 1.50.

For plywood of five or more plies with the grain of the face plies perpendicular to the span, K equals 0.85.

The foregoing formula assumes that the moment of inertia is calculated on the basis of actual ply thicknesses.

It is present commercial practice to sand either one or both faces of structural plywood and the thickness of these faces are appreciably reduced thereby. Furthermore, the thickness of plies running in one direction may be different from that of the plies running in the opposite direction. It is apparent from this discussion that the moment of inertia of commercial five-ply, ½-inch plywood, for example, cannot be calculated on the assumption that each ply is one-tenth inch in thickness.

Defects in the plies adjacent to the faces have but little influence upon the bending strength when the grain of the face plies is parallel to the span. When the grain of the face plies is not parallel to the span and the plies adjacent to the faces contain defects, such as knots or severe cross grain, the bending strength is much less than when the plies adjacent to the face plies are of clear straight-grained veneer.

SHEAR STRENGTH

If shearing forces are applied to plywood its shear strength will depend upon the direction of the shearing forces with respect to the grain of the plies and upon the size of the unsupported area of plywood subjected to shear. Thus, in figure 41 the shear strength will depend upon the direction of the grain in the plies with respect to the direction of the shearing forces indicated by the large arrows, upon the dimension (a) between the two timbers, and upon the spacing of any struts or diaphragms used to span the gap (a).

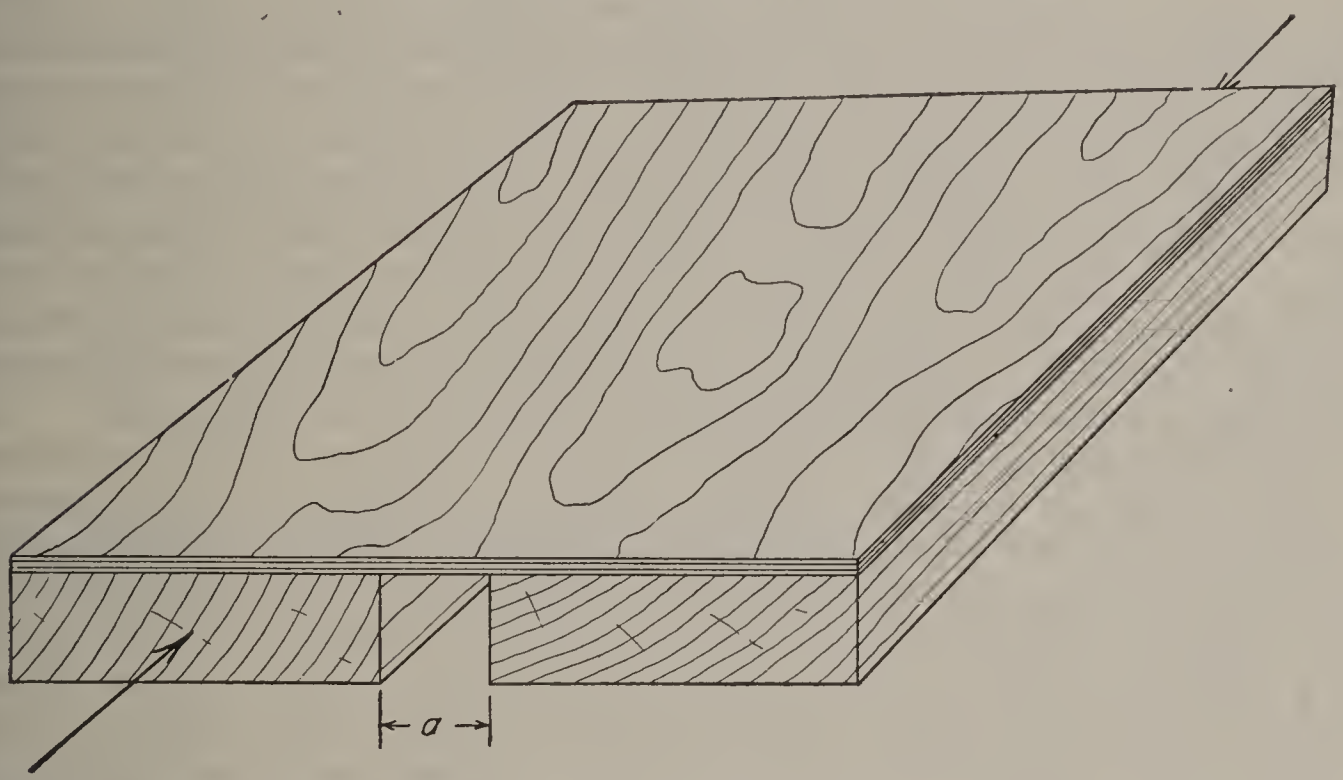


FIGURE 41.—The shear strength of plywood depends upon the direction of the grain in the plies with respect to the direction of the shearing forces indicated by the large arrows, upon the dimension (a) between the two timbers, and the spacing of the struts or diaphragms used to span the gap (a).

If the distance (a) is not more than one-fourth inch and no struts or blocks are used to prevent the two timbers from coming closer together as load is applied, the shearing strength of plywood will be about 1¾ times that listed for ordinary wood along the grain (p. 50) when the applied forces act either parallel or perpendicular to the grain of the face plies. With this same limitation on the distance (a), the shearing strength of plywood will be about 3½ times that of ordinary wood along the grain when the grain of the plies is at 45° with the applied forces.

As the dimension (a) is increased buckling of the plywood under stress will become more pronounced and the ultimate shearing strength will be reduced. If the dimension (a) is 6 or 8 inches and no blocks or struts are placed in the gap (a), plywood acted upon by shearing forces parallel or perpendicular to the grain of the plies will have about 1⅙ the shearing strength of solid wood parallel to the grain, and that acted upon by forces at 45° to the grain of the plies will have about 1⅓ the shearing strength of solid wood.

If struts or diaphragms are spaced in the gap (a) at intervals not more than 1½ times the dimension (a), the shearing strength of plywood either parallel or perpendicular to the grain of the plies will be about 1¾ times that of ordinary wood while the shearing strength at 45° with the grain will be about 2 times that of ordinary wood.

RIGIDITY OF STRUCTURAL SHEETS

Plywood used in large structural sheets, as for house sheathing, can contribute great strength and rigidity to the structure if well nailed, glued, or otherwise securely attached to the framework. Tests were made at the Forest Products Laboratory on wall panels sheathed horizontally with 8-inch boards nailed to studs spaced 16 inches with two eightpenny nails per board at each stud crossing, and on similar wall panels sheathed with ¼-inch, 3-ply Douglas fir plywood nailed with sixpenny nails spaced 5 inches along the four edges of each sheet and 10 inches on intermediate studs. These tests show the rigidity of the plywood walls, as regards loads acting in the plane of the wall, to be 4 to 5 times that for the horizontal sheathing and the ultimate strength to be more than 5 times as much.

A wall panel sheathed with ⅝-inch plywood nailed to the studs with eightpenny nails spaced 6 inches along the four edges of each sheet and 12 inches on intermediate studs was but slightly more rigid at small distortions than one sheathed with ¼-inch plywood as just described. The loads at the larger distortions and the maximum load were considerably greater for the thicker plywood.

These results indicate that the rigidity supplied to the structure by the plywood depends largely upon the method of attachment; in this particular instance, upon the lateral resistance of the nails. As pointed out under the discussion of nails (p. 123), their safe lateral resistance varies as the 3/2 power of the diameter. The diameter of a sixpenny common wire nail is 0.113 inch and that of an eightpenny nail 0.131 inch. The number of nails used with the two panels just mentioned was as 5 to 6. Therefore, the rigidity at small distortions of the ⅝-inch plywood panel as compared with that sheathed with ¼-inch plywood would be

$$\left(\frac{0.131}{0.113}\right)^{3/2}\times\frac{5}{6}=1.04$$

Tests of still other panels showed that the rigidity of a panel with the plywood glued to the studs was several times as great as when it was nailed.

SPLITTING RESISTANCE

Plywood permits fastening with nails or screws close to the edges because it offers much greater resistance to splitting than ordinary wood. Also, because of the equalization of strength properties along and across a sheet and the resistance to splitting resulting from the crossbanded construction, plywood panels covering relative large areas are less liable to damage from concentrated or impact loads than similar panels made of ordinary lumber.

In removing nails from plywood some care must be used to pull them straight out or nearly so, because splintering of the outside ply may result if the nails are pulled or pried out at an angle.

SHRINKAGE OF PLYWOOD

The shrinkage of plywood varies with the species, the ratios of ply thicknesses, the number of plies, and the combination of species. The average shrinkage values obtained at the Forest Products Lab-

oratory in drying, from a soaked to an oven-dry condition, three-ply panels having all plies in any one panel of the same thickness and species was about 0.45 percent parallel to the face grain and 0.67 percent perpendicular to the face grain, with ranges of from 0.2 to 1 percent and 0.3 to 1.2 percent, respectively. The panels tested ranged in thickness from one-tenth- to one-half-inch. The shrinkage parallel and perpendicular to the face grain of plywood made of 5 or more plies is more nearly equal than that made of 3 plies.

GLUED LAMINATED CONSTRUCTION

Parallel-grain or laminated construction (fig. 42), as distinguished from crossbanded construction, refers to two or more layers of wood glued together with the grain of all layers approximately parallel. The laminations may vary as to species, number, size, shape, and thickness. Parallel-grain construction finds extensive use as cores for veneered panels and in many unveneered products.

For best results in making laminated glued products it is important to avoid as much as possible the development of internal stresses when the article is exposed to conditions that change its moisture content. Differences in shrinking and swelling are the fundamental causes of internal stresses, and laminations should be of such character that they shrink or swell similar amounts in the same direction.

Gluing together laminations of the same species, or of different species that have similar shrinkage characteristics, of all flat-grained or all edge-grained material, and of the same moisture content produces constructions that are the freest from stresses on the glued joints with a minimum of tendency to change shape or the joints to open.

Laminations that have an abnormal tendency to shrink endwise, from such causes as excessive cross grain or the presence of compression wood (p. 65), should not be included in constructions that must remain flat. Their inclusion may result in serious bowing or cupping of the laminated members.

STRENGTH OF GLUED LAMINATED WOOD

The properties of parallel-grain constructions are essentially the same as those of solid wood (p. 149) but laminated members, if well constructed, are usually more uniform in strength properties and less apt to change shape with variations in moisture content.

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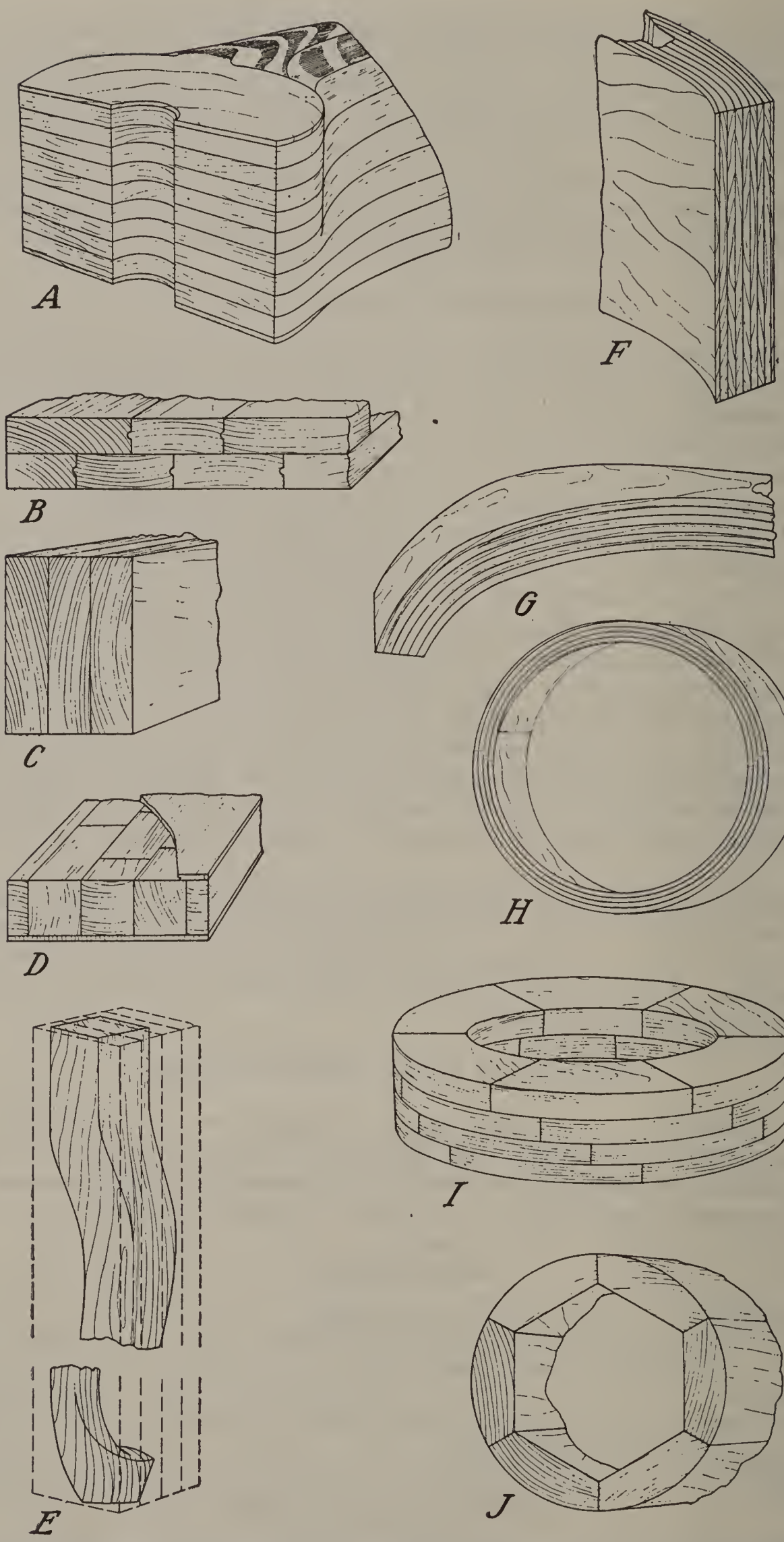


FIGURE 42.—Types of parallel-grain construction: *A*, section of airplane propeller hub; *B*, section of table top; *C*, section of automobile sill; *D*, section of door stile or rail; *E*, chair leg; *F*, section of grand piano; *G*, section of automobile cowl; *H*, wrapped-veneer banjo rim; *I*, pulley rim; *J*, section of a column.

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BENT WOOD MEMBERS

Curved members of wood are produced by band sawing or by bending. Band-sawed parts are subject to splitting and breaking because the direction of the grain does not follow the curvature of the piece. Bent parts are free from this objection and are ordinarily much more serviceable. They are formed either by bending a single piece or by bending and gluing laminations sufficient in number to make up the required thickness.

SOLID PIECES OF FULL SIZE

BENDING PROCEDURE

In making single-piece bent members the stock must be softened to permit the required deformation (Wilson).[31] The usual agencies are steam and hot water. Wood can be stretched only a small amount, about 1 percent, without tension failure. When properly softened, however, some species can be compressed as much as 25 percent.

Because of the relation between attainable tensile and compressive deformations, it is necessary, when bending involves severe deformation, that most of the deformation be forced to take place as compression. This result is accomplished by the use of metal straps on the convex side of the piece. Special appliances and skillful manipulation are necessary to get proper action from these straps and to prevent the compression from becoming localized, thus producing irregularities of curvature and disfiguring wrinkles.

SELECTION OF STOCK

Straight-grained material free from defects is essential for bends that involve extreme deformations. Where the bends are not extreme, irregularities of grain and small knots may be permitted on the tension side of the piece provided efficient straps are used on that side. Knots or other defects that interfere with uniform shortening are undesirable on the compression side.

Considerable variation in the weight, hardness, and strength occurs in all species. The heavier stock is ordinarily the harder and stronger and hence more serviceable in bent articles in which these properties are desirable. Information is not available to show definitely what quality of wood can be bent most successfully. In hickory, the most flexible material is usually that from near the base of the tree and the same is probably true of other species ordinarily used in bending, except that wood from near the base of swamp-grown trees is often low in density and strength properties.

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[31] For further information, the references at the end of this section should be consulted.

CHOICE OF SPECIES

In general, the hardwoods are more readily softened by the action of heat and moisture and are more suitable than conifers for bends involving large deformation. Also hardwoods are frequently preferred because of their appearance or other characteristics and are used more extensively than the conifers. The elms, the ashes, and the true and pecan hickories are preferred for bending that requires extreme deformation. The oaks, beech, birches, maples, and red gum are largely used for bent parts of chairs and other furniture. Douglas fir and southern yellow pine are used for planking and other bent parts of wood ships where large sizes with moderate bends are required.

CHARACTERISTICS OF BENT WOOD

Wood that has been steam bent and dried while held to shape tends to bend more with further drying or to straighten with the absorption of moisture. Thus bent wood should preferably be dried on the forms or otherwise held to the desired shape until approximately the moisture content it will have in service is reached.

If moisture is absorbed while a piece of bent wood is held against straightening, the tendency of the concave side to swell may produce sufficient stress to cause tension failure at the convex face, hence the need for caution in steaming wood during the drying process and for protecting bent parts from large changes in moisture content.

In most bends the deformation is far beyond the proportional limit and well beyond the deformation at maximum stress; consequently the strength of bent pieces is less than that of straight pieces. The reduction in strength is related to the deformation produced in bending. The excellent service given by steam-bent parts, however, indicates that the lowered strength values do not destroy the usefulness of such parts for many purposes.

LAMINATED MEMBERS

Laminated curved members are produced from dry stock by bending and gluing together in one operation several comparatively thin pieces without softening them by steam or hot water. This process has the following advantages over the bending of single-piece members: (1) The laminations can be made so thin that bending to the required radius involves only moderate stress and deformation of the wood fibers; consequently, the use of steam or hot water is unnecessary and less subsequent drying and conditioning is required; (2) because of the moderate stress induced in bending, stronger parts are produced; (3) the tendency of laminated members to change shape with changes in moisture content resulting from changes in relative humidity is less than that of single-piece bent members and can be made negligible by making the laminations thin in comparison with the radius; (4) ratios of thickness of member to radius of curvature that are impossible in bending single pieces can readily be obtained by laminating; also members having reversed curvature are more readily made by laminating thin plies, and curved parts of any desired length can be produced by staggering the joints in the laminations.

Softwoods are ordinarily used for laminated bent structural members, and thin material of any of the softwoods can be satisfactorily bent for such purposes. The choice of species is dependent primarily upon the cost and required strength.

Laminating of curved pieces in the United States has been applied chiefly to comparatively small parts, such as those in furniture and pianos. The principle is gradually being extended, however, to the construction of wood arches for use as roof supports in industrial and public-assembly buildings. Results of tests bearing on such uses are discussed on page 168.

VENEERED CURVED MEMBERS

Veneered curved members are usually produced by gluing veneer to one or both faces of a curved solid wood base (Perry). The bases are ordinarily band sawn to the desired shape or bent from a piece grooved with saw kerfs on the concave side at right angles to the directions of bend. Sometimes series of curved pieces are band sawn contiguously from the same block of wood and reassembled in a gluing operation in the same relative position with glue-coated pieces of veneer between, thus producing a number of similar veneered curved pieces in one operation. Pressure is then applied to the whole series. In other assemblies single members are band sawn to the desired curvature and then faced with a layer of veneer, and pressure is applied by means of flexible bands and clamps while the glue sets. Pieces, bent by making saw kerfs on the concave side, are commonly reinforced and kept to the required curvature by gluing splines, veneer, or other pieces to the curved base.

Veneering over curved solid wood finds use mainly in furniture. The grain of the veneer is commonly laid in the same general direction as the grain of the curved wood base. The use of crossband veneers, that is, veneers laid with the grain at right angles to the grain of the base and face veneer, reduces the tendency of the member to split.

PLYWOOD CURVED MEMBERS

Plywood curved members are produced (1) by bending and gluing in one operation, and (2) by bending plywood after gluing.

PLYWOOD BENT AND GLUED SIMULTANEOUSLY

In bending and gluing plywood in a single operation the glue-coated pieces are assembled and pressed over or between curved forms until the glue sets and holds the assembly to the desired curvature (Truax). Some of the laminations are at an angle, usually 90°, to the grain of the other laminations. The thicker laminations, at least most of them, are at right angles to the direction of curvature in order to facilitate bending. Individual laminations from one thirty-second to one-eighth inch thick are readily bent and glued, though the maximum curvature obtainable varies with the thickness. Individual laminations from three-sixteenths to one-fourth inch thick may be bent and glued only to curvatures of large radiuses.

The advantages of plywood bent and glued simultaneously are similar to those for laminated members (p. 188) and in addition, the

cross plies give the curved members properties characteristic of crossband plywood construction (p. 177).

PLYWOOD BENT AFTER GLUING

Thin plywood and other thin glued members are occasionally bent to moderate curvatures after the plies are glued together by methods that are similar to those used in bending solid wood. Water-resistant plywood panels are bent to moderate double curvatures by soaking and steaming and pressing between heated forms. The process is not adapted to plywood glued with non-water-resistant glues. Another process consists in bending dry plywood by passing it between hot rollers (Perry, third reference). Both processes find use only in limited fields.

The use of hardwoods predominates in the manufacture of curved plywood, though selected softwoods are used in certain specialized fields, such as aircraft manufacture.

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CONTROL OF MOISTURE CONTENT AND SHRINKAGE OF WOOD

EQUILIBRIUM MOISTURE CONTENT

Any piece of wood will give off or take on moisture from the surrounding atmosphere until the moisture in the wood has come to a balance with that in the atmosphere. The moisture in the wood at the point of balance is called the equilibrium moisture content.

Assuming constant temperature, the ultimate moisture content that a given piece of wood will attain depends entirely upon the relative humidity of the atmosphere surrounding it, which is the amount of

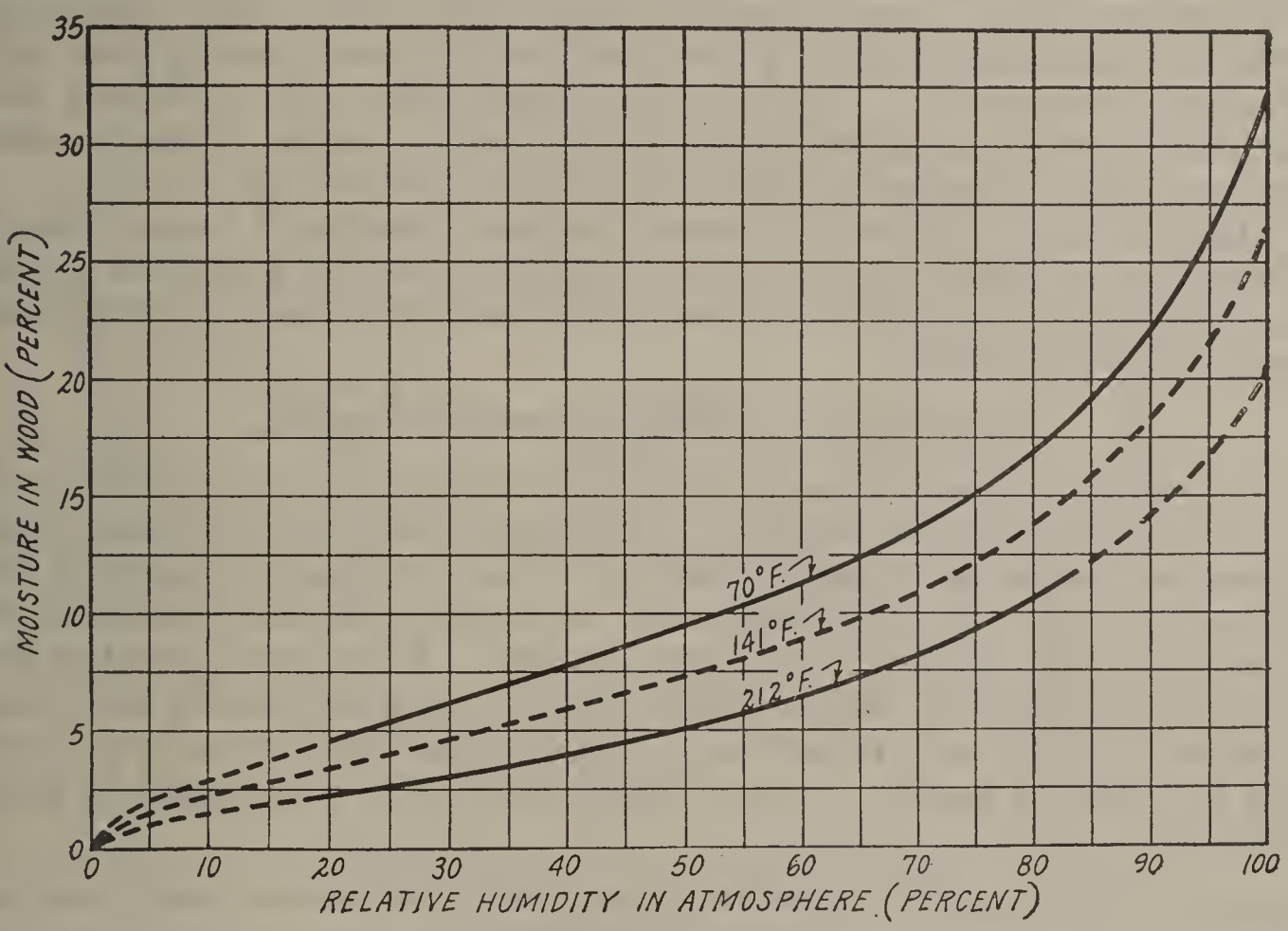


FIGURE 43.—Relation of the equilibrium moisture content of wood to the relative humidity of the surrounding atmosphere at three temperatures.

vapor in the air expressed as a percentage of the amount it would hold at saturation. This relationship is illustrated by figure 43, which shows, for example, that wood kept in an atmosphere constantly at 70° F. and 60-percent relative humidity will eventually come to a moisture content of about 11 percent.

Changes in the relative humidity of the atmosphere range from the usual daily fluctuations to marked seasonal variations. Thus wood, when exposed to ordinary atmospheric conditions, is virtually always undergoing at least slight changes in moisture content because of its tendency to come to a balance with the surrounding air. The change, however, is a very gradual one and is further retarded by protective coatings such as varnish or paint. The practical objective of all correct seasoning and handling methods is to minimize moisture variations in wood by simple means of control that will adapt the material most fully to average atmospheric conditions in service.

RECOMMENDED MOISTURE CONTENT

The percentages of moisture content here recommended for wood are selected primarily for the purpose of reducing changes in moisture content to a minimum, thereby minimizing dimensional changes after the wood is put into service (Peck).[32]

TIMBERS

Ordinarily a timber should be seasoned to as low a moisture content as it will ultimately come to in service, or as near this condition as practical. While this optimum may be possible in small and medium-sized timbers, it is seldom possible to obtain large timbers fully seasoned. In the construction of unheated buildings, such as warehouses, large green timbers often dry with fewer seasoning defects after being put in place than would result under poor air-seasoning conditions. Therefore, if there is no decay hazard and shrinkage is not a serious factor, it generally proves entirely satisfactory to use unseasoned timbers in such construction (p. 199).

Material used for roof trusses, arches, laminated floors, heavy plank flooring, bridge members, derricks, and similar purposes should be seasoned to a moisture content corresponding to service conditions before it is assembled.

LUMBER FOR EXTERIOR OR INTERIOR SERVICE

The moisture-content requirements for finish lumber or wood products to be used in the interior of buildings are more exacting than those for lumber or wood products used out of doors because of the higher character of the service and because wood used out of doors does not reach so low a moisture content. In general, lumber for exterior and interior use should be dried to approximately the value to which it will come in service. These values are for various items and for various regions in the United States and are shown in table 41.

TABLE 41.—*Recommended moisture-content values for various wood items at time of installation*

Use of lumber	Moisture content (percentage of weight of oven-dry wood) for—					
	Dry Southwestern States [1]		Damp Southern coastal States [1]		Remainder of the United States [1]	
	Average [2]	Individual pieces	Average [2]	Individual pieces	Average [2]	Individual pieces
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Interior finish woodwork and softwood flooring	6	4–9	11	8–13	8	5–10
Hardwood flooring	6	5–8	10	9–12	7	6–9
Siding, exterior trim, sheathing, and framing [3]	9	7–12	12	9–14	12	9–14

[1] For limiting range see fig. 44.

[2] In general, the moisture-content averages have less significance than the range in moisture content permitted in individual pieces. If the moisture-content values of all the pieces in a lot fall within the prescribed range, the entire lot will be satisfactory as to moisture content no matter what its average moisture content may be.

[3] Framing lumber of higher moisture content is commonly used in ordinary construction because material of the moisture content specified may not be available except on special order.

[32] For further information, the references at the end of this section should be consulted.

It is the general commercial practice to dry some wood products, such as flooring (Teesdale, Leaflet 56) and furniture wood to a lower moisture content than service conditions demand, counting on a moderate increase in moisture content during the storage and manufacturing period. This practice is intended to assure a uniform distribution of moisture among the individual pieces. Other wood products, such as finish and millwork lumber, are not seasoned to so low a moisture content. Common grades and rough construction lumber are not ordinarily seasoned to the moisture-content values indicated in table 41. The design of the structure, as explained on page 198, should take account of this condition in such a way as to minimize shrinkage effects.

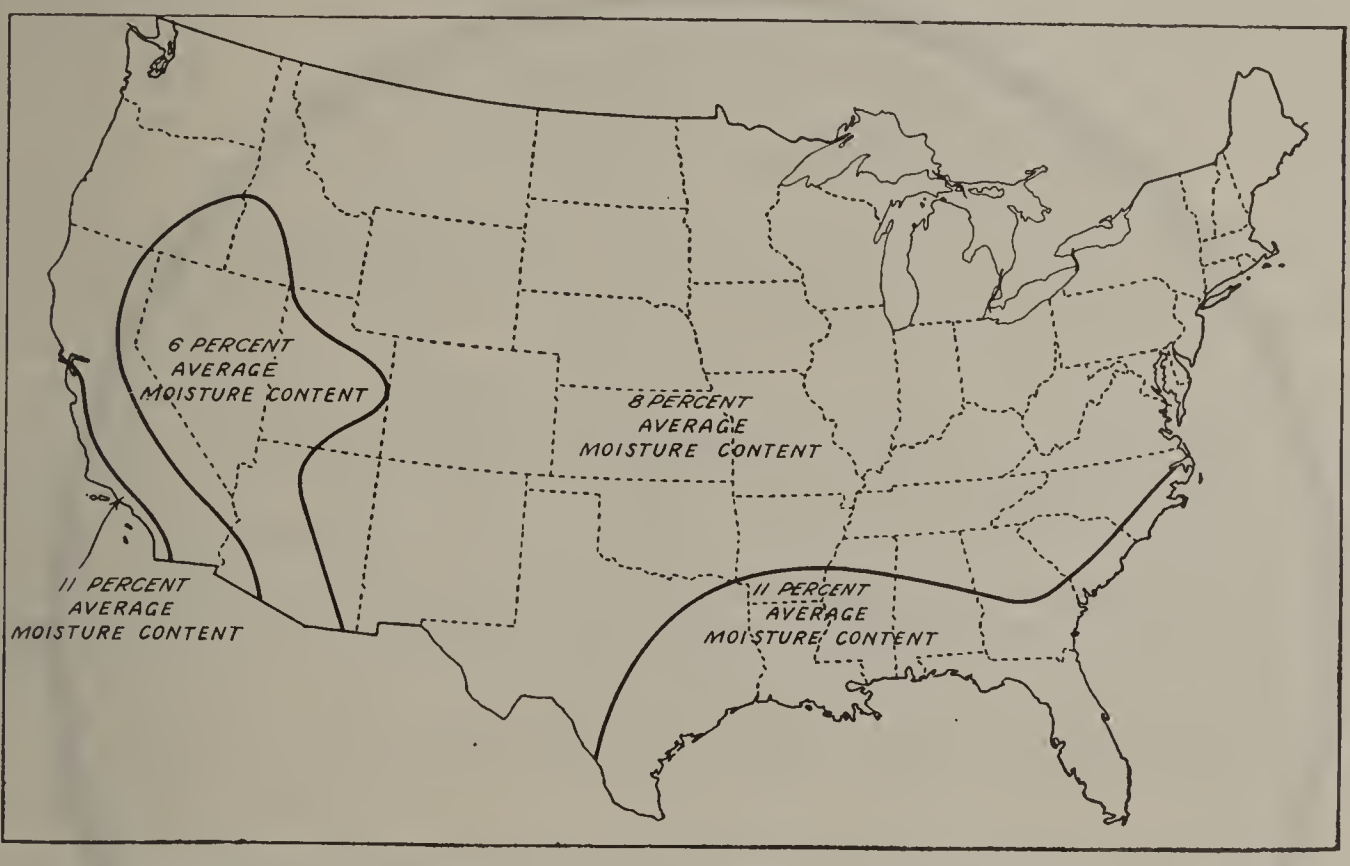


FIGURE 44.—Recommended moisture-content averages for interior-finishing woodwork for use in various parts of the United States.

VENEER AND PLYWOOD

When veneers are glued with ordinary glues they absorb large quantities of moisture during the operation. To keep the final moisture content low and to minimize redrying of the plywood the initial moisture content of the veneer should be as low as practicable. Very dry veneer, however, is difficult to handle without cracking so that the minimum practicable moisture content is between 4 and 5 percent. After gluing, plywood intended for interior service should be redried to the moisture values that are given in table 41 for interior lumber. If adhesives containing no water are used, the veneer need only be dried to a moisture-content value in accordance with its service requirements, and redrying is unnecessary.

SHRINKAGE OF WOOD

Wood, like many other materials, shrinks as it loses moisture and swells as it absorbs moisture.

While wood in its green condition as it comes from the tree may contain from 30 to 250 percent water (Mathewson, and Thelen),

based on the weight of the oven-dry wood, the removal of only the last 25 or 30 percent of this moisture content has the effect of shrinking the wood on drying out; and since wood in service is never totally dry, the possible shrinkage effect falls within a relatively narrow range. Water is held in the wood in two distinct ways—imbibed water in the walls of the wood cells, and free water in the cell cavities. When wood begins to dry the free water leaves first, followed by the imbibed water. The fiber-saturation point is that condition in which all the free water has been removed but all the imbibed water remains; for most woods this point is between 25- and 30-percent moisture content.

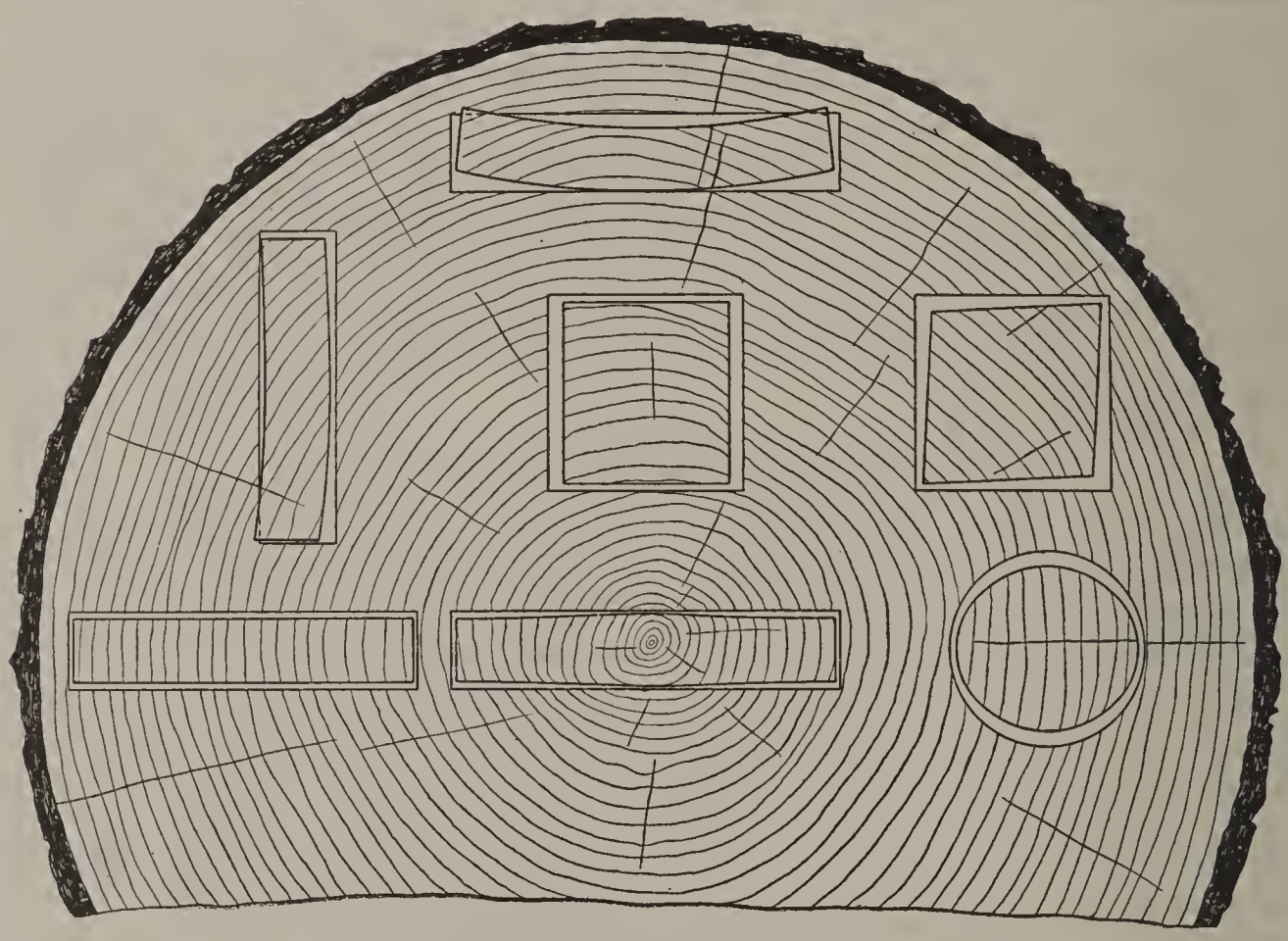


FIGURE 45.—Characteristic shrinkage and distortion of flats, squares, and rounds as affected by the direction of the annual rings. Tangential shrinkage is about twice as great as radial.

Wood changes size with moisture content only below the fiber-saturation point. Since in seasoning green wood the surface dries more rapidly than the interior and reaches the fiber-saturation point first, shrinkage may start while the average moisture content is considerably above the fiber-saturation point. Wood shrinks most in the direction of the annual growth rings (tangentially), about one-half to two-thirds as much across these rings (radially), and very little, as a rule, along the grain (longitudinally). The joint effects of radial and tangential shrinkage on the shape of various sections in drying from the green condition are illustrated in figure 45. When a board is excessively cross-grained the lengthwise shrinkage is a combination of crosswise and longitudinal shrinkage, resulting in a greater shortening than would occur in a straight-grained piece. Shrinkage is usually expressed as a percentage of the green dimensions, which represent the natural size of the piece. Table 42 gives the range in shrinkage in different directions for most of the commercially important native species.

TABLE 42.—*Range in average shrinkage of a number of native species of wood*

Direction of shrinkage	From green to oven-dry condition	From green to air-dry condition (12- to 15-percent moisture content)
	Percent of green size	*Percent of green size*
Tangential	4.3 to 14	2.1 to 7
Radial	2 to 8.5	1 to 4.2
Longitudinal	.1 to .2	.05 to .1
Volumetric	7 to 21	3.5 to 10.5

Shrinkage in drying is proportional to the moisture lost below the fiber-saturation point. Approximately one-half the total shrinkage possible has occurred in wood seasoned to an air-dry condition (12- to 15-percent moisture content) and about three-fourths in lumber kiln dried to a moisture content of about 7 percent. Hence, if wood is properly seasoned, manufactured, and installed at a moisture content in accord with its service conditions, there is every prospect of satisfactory performance without serious changes in size or distortion of section.

In general, the heavier species of wood shrink more across the grain than the lighter ones. Heavier pieces also shrink more than lighter pieces of the same species. When shrinkage is more of a factor than hardness or strength a lightweight species should be chosen. When both hardness or strength and low shrinkage are very important then an exceptional species, such as black locust, should be chosen.

The average tangential, radial, and volumetric shrinkages for individual species dried to an air-dry, kiln-dry, or oven-dry condition are given in table 43.

TABLE 43.—*Shrinkage values for commercially important woods grown in the United States*

Species	Shrinkage (percent of dimension when green) from green to—								
	Air dried to 12- to 15-percent moisture [1] (estimated values)			Kiln dried to 6- to 7-percent moisture [2] (estimated values)			Oven dried to 0-percent moisture (test values)		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Alder, red	2.2	3.6	6.3	3.3	5.5	9.4	4.4	7.3	12.6
Ash:									
Black	2.5	3.9	7.6	3.8	5.8	11.4	5.0	7.8	15.2
Commercial white [3]	2.3	3.8	6.4	3.4	5.6	9.6	4.6	7.5	12.8
Oregon	2.0	4.0	6.6	3.1	6.1	9.9	4.1	8.1	13.2
Aspen	1.8	3.4	5.8	2.6	5.0	8.6	3.5	6.7	11.5
Basswood	3.3	4.6	7.9	5.0	7.0	11.8	6.6	9.3	15.8
Beech	2.6	5.5	8.2	3.8	8.2	12.2	5.1	11.0	16.3
Birch [4]	3.4	4.4	8.2	5.2	6.7	12.2	6.9	8.9	16.3
Birch, paper	3.2	4.3	8.1	4.7	6.4	12.2	6.3	8.6	16.2
Butternut	1.6	3.0	5.1	2.5	4.6	7.6	3.3	6.1	10.2

[1] These shrinkage values have been taken as ½ the shrinkage to the oven-dry condition as given in the last 3 columns of this table.

[2] These shrinkage values have been taken as ¾ the shrinkage to the oven-dry condition as given in the last 3 columns of this table.

[3] Average of Biltmore white ash, blue ash, green ash, and white ash.

[4] Average of sweet birch and yellow birch.

TABLE 43.—*Shrinkage values for commercially important woods grown in the United States*—Continued

Species	Shrinkage (percent of dimension when green) from green to—								
	Air dried to 12- to 15-percent moisture (estimated values)			Kiln dried to 6- to 7-percent moisture (estimated values)			Oven dried to 0-percent moisture (test values)		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Cedar:									
Alaska	1.4	3.0	4.6	2.1	4.5	6.9	2.8	6.0	9.2
Eastern red	1.6	2.4	3.9	2.3	3.5	5.8	3.1	4.7	7.8
Incense	1.6	2.6	3.8	2.5	3.9	5.7	3.3	5.2	7.6
Northern white	1.0	2.4	3.5	1.6	3.5	5.2	2.1	4.7	7.0
Port Orford	2.3	3.4	5.0	3.4	5.2	7.6	4.6	6.9	10.1
Southern white	1.4	2.6	4.2	2.1	3.9	6.3	2.8	5.2	8.4
Western red	1.2	2.5	3.8	1.8	3.8	5.8	2.4	5.0	7.7
Cherry, black	1.8	3.6	5.8	2.8	5.3	8.6	3.7	7.1	11.5
Chestnut	1.7	3.4	5.8	2.6	5.0	8.7	3.4	6.7	11.6
Cottonwood:									
Eastern	2.0	4.6	7.0	2.9	6.9	10.6	3.9	9.2	14.1
Northern black	1.8	4.3	6.2	2.7	6.4	9.3	3.6	8.6	12.4
Cypress, southern	1.9	3.1	5.2	2.8	4.6	7.9	3.8	6.2	10.5
Douglas fir:									
Coast region	2.5	3.9	5.9	3.8	5.8	8.8	5.0	7.8	11.8
"Inland Empire" region	2.0	3.8	5.4	3.1	5.7	8.2	4.1	7.6	10.9
Rocky Mountain region	1.8	3.1	5.3	2.7	4.6	8.0	3.6	6.2	10.6
Elm:									
American	2.1	4.8	7.3	3.2	7.1	11.0	4.2	9.5	14.6
Rock	2.4	4.0	7.0	3.6	6.1	10.6	4.8	8.1	14.1
Slippery	2.4	4.4	6.9	3.7	6.7	10.4	4.9	8.9	13.8
Fir:									
Balsam	1.4	3.3	5.4	2.1	5.0	8.1	2.8	6.6	10.8
Commercial white [5]	1.6	3.6	4.9	2.4	5.3	7.4	3.2	7.1	9.8
Gum:									
Black	2.2	3.8	7.0	3.3	5.8	10.4	4.4	7.7	13.9
Red	2.6	5.0	7.5	3.9	7.4	11.2	5.2	9.9	15.0
Tupelo	2.1	3.8	6.2	3.2	5.7	9.4	4.2	7.6	12.5
Hackberry	2.4	4.4	6.9	3.6	6.7	10.4	4.8	8.9	13.8
Hemlock:									
Eastern	1.5	3.4	4.8	2.2	5.1	7.3	3.0	6.8	9.7
Western	2.2	4.0	6.0	3.2	5.9	8.9	4.3	7.9	11.9
Hickory:									
Pecan [6]	2.4	4.4	6.8	3.7	6.7	10.2	4.9	8.9	13.6
True [7]	3.6	5.7	9.0	5.5	8.6	13.4	7.3	11.4	17.9
Honey locust	2.1	3.3	5.4	3.2	5.0	8.1	4.2	6.6	10.8
Larch, western	2.1	4.0	6.6	3.2	6.1	9.9	4.2	8.1	13.2
Locust, black	2.2	3.4	4.9	3.3	5.2	7.4	4.4	6.9	9.8
Magnolia:									
Cucumber	2.6	4.4	6.8	3.9	6.6	10.2	5.2	8.8	13.6
Evergreen	2.7	3.3	6.2	4.0	5.0	9.2	5.4	6.6	12.3
Maple:									
Bigleaf	1.8	3.6	5.8	2.8	5.3	8.7	3.7	7.1	11.6
Black	2.4	4.6	7.0	3.6	7.0	10.5	4.8	9.3	14.0
Red	2.0	4.1	6.6	3.0	6.2	9.8	4.0	8.2	13.1
Silver	1.5	3.6	6.0	2.2	5.4	9.0	3.0	7.2	12.0
Sugar	2.4	4.8	7.4	3.7	7.1	11.2	4.9	9.5	14.9
Oak:									
Red [8]	2.2	4.5	7.4	3.2	6.8	11.1	4.3	9.0	14.8
White [9]	2.7	4.6	8.0	4.0	7.0	12.0	5.4	9.3	16.0
Pine:									
Loblolly	2.4	3.7	6.2	3.6	5.6	9.2	4.8	7.4	12.3
Lodgepole	2.2	3.4	5.8	3.4	5.0	8.6	4.5	6.7	11.5
Longleaf	2.6	3.8	6.1	3.8	5.6	9.2	5.1	7.5	12.2
Northern white	1.2	3.0	4.1	1:7	4.5	6.2	2.3	6.0	8.2
Norway	2.3	3.6	5.8	3.4	5.4	8.6	4.6	7.2	11.5
Ponderosa	2.0	3.2	4.8	2.9	4.7	7.2	3.9	6.3	9.6
Shortleaf	2.2	3.8	6.2	3.3	5.8	9.2	4.4	7.7	12.3
Sugar	1.4	2.8	4.0	2.2	4.2	5.9	2.9	5.6	7.9
Western white	1.3	2.6	5.9	2.0	4.0	8.8	2.6	5.3	11.8
Poplar, yellow	2.0	3.6	6.2	3.0	5.3	9.2	4.0	7.1	12.3
Redwood	1.3	2.2	3.4	2.0	3.3	5.1	2.6	4.4	.86

[5] Average of lowland white fir and white fir.
[6] Average of bitternut hickory, nutmeg hickory, water hickory, and pecan.
[7] Average of bigleaf shagbark hickory, mockernut hickory, pignut hickory, and shagbark hickory.
[8] Average of black oak, laurel oak, pin oak, red oak, scarlet oak, southern red oak, swamp red oak, water oak, and willow oak.
[9] Average of bur oak, chestnut oak, post oak, swamp chestnut oak, swamp white oak, and white oak.

TABLE 43.—*Shrinkage values for commercially important woods grown in the United States*—Continued

Species	Shrinkage (percent of dimension when green) from green to—								
	Air dried to 12- to 15-percent moisture (estimated values)			Kiln dried to 6- to 7-percent moisture (estimated values)			Oven dried to 0-percent moisture (test values)		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
Spruce:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Eastern [10]	2.2	3.8	6.3	3.2	5.8	9.4	4.3	7.7	12.6
Engelmann	1.7	3.3	5.2	2.6	5.0	7.8	3.4	6.6	10.4
Sitka	2.2	3.8	5.8	3.2	5.6	8.6	4.3	7.5	11.5
Sugarberry	2.5	3.6	6.4	3.8	5.5	9.5	5.0	7.3	12.7
Sycamore	2.6	3.8	7.1	3.8	5.7	10.6	5.1	7.6	14.2
Tamarack	1.8	3.7	6.8	2.8	5.6	10.2	3.7	7.4	13.6
Walnut, black	2.6	3.6	5.6	3.9	5.3	8.5	5.2	7.1	11.3

[10] Average of black spruce, red spruce, and white spruce.

Theoretically the normal moisture content-shrinkage relation may be considered a direct one, from zero shrinkage at the fiber-saturation point to maximum shrinkage at zero moisture content. Actually the relationship in lumber of commercial size is similar to the curves in figure 46, but for practical use a straight-line relation may be assumed without appreciable error. The curves represent average values, and the shrinkage of an individual board may, of course, be above or below the amount indicated.

Changes in moisture content in seasoned wood, such as those caused by seasonal variation in relative humidity, produce changes in dimension proportional to the moisture-content changes. For example, assume that a piece of flat-sawed southern yellow pine sheathing at 12 percent moisture content loses 5 percent

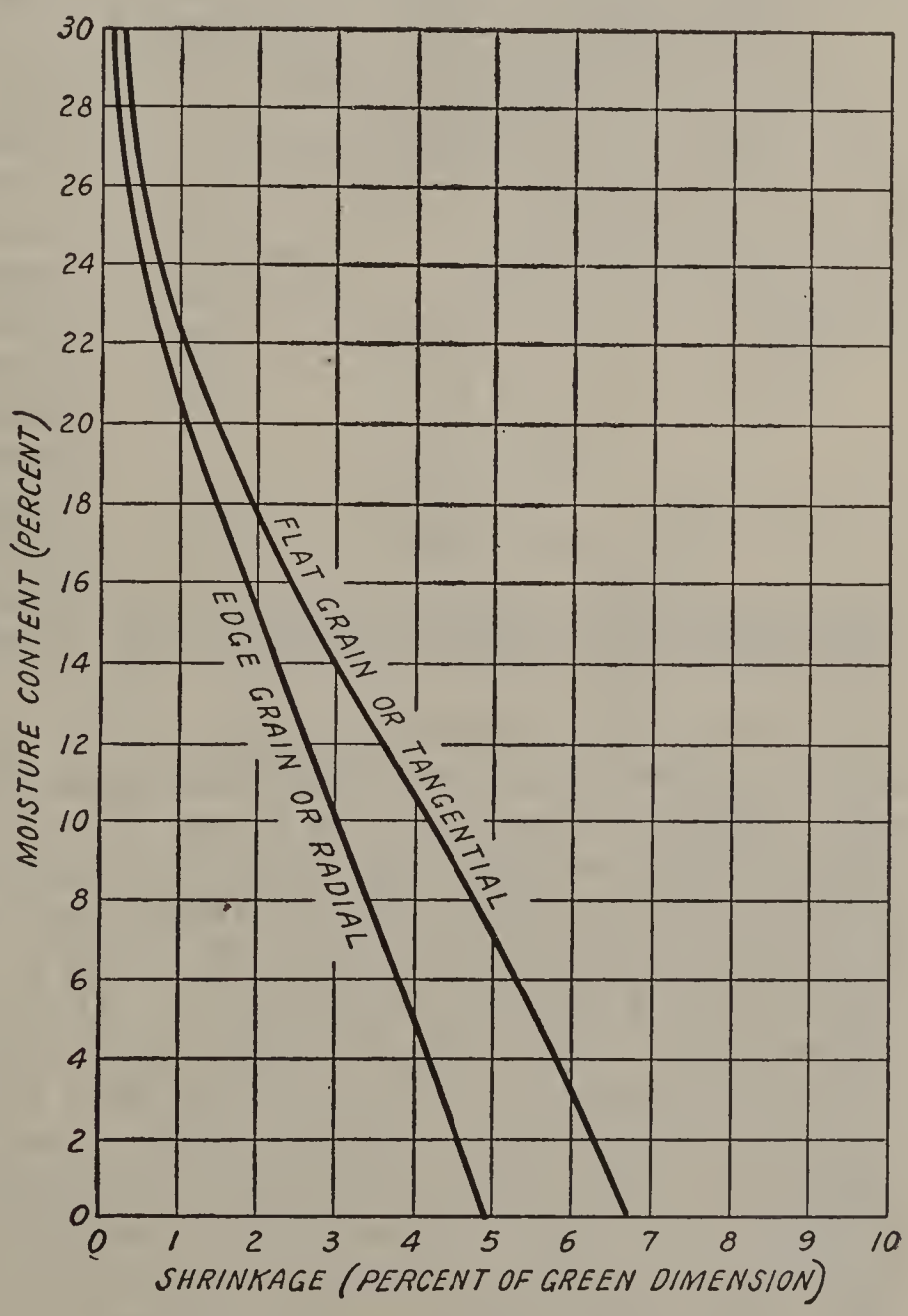


FIGURE 46.—Typical moisture-shrinkage curves. These curves are for Douglas fir and southern yellow pine and may be used for estimating the amount of change in dimension that will take place with change in the moisture content of the wood.

of moisture. The shrinkage curve (marked "tangential") indicates that from the green condition to 7 percent moisture content the shrinkage in width would be 5 percent and to 12-percent moisture content would be 3½ percent. The difference of 1½ percent indicates the shrinkage in width of the board because of the 5 percent loss in moisture. These curves represent average values, and the shrinkage of an individual board may be below or above the indicated amount.

DESIGN FACTORS AFFECTING SHRINKAGE IN THE STRUCTURE

STRUCTURAL LUMBER IN FRAME HOUSE CONSTRUCTION

The most effective method of minimizing shrinkage or settlement in the frame is to use structural lumber seasoned to suit the use requirements (table 41). Any of the standard forms of construction (National Lumber Manufacturers' Association, National Committee on Wood Utilization, and Weyerhauser Forest Products) can be used if the joists and studs are seasoned to the moisture content recommended.

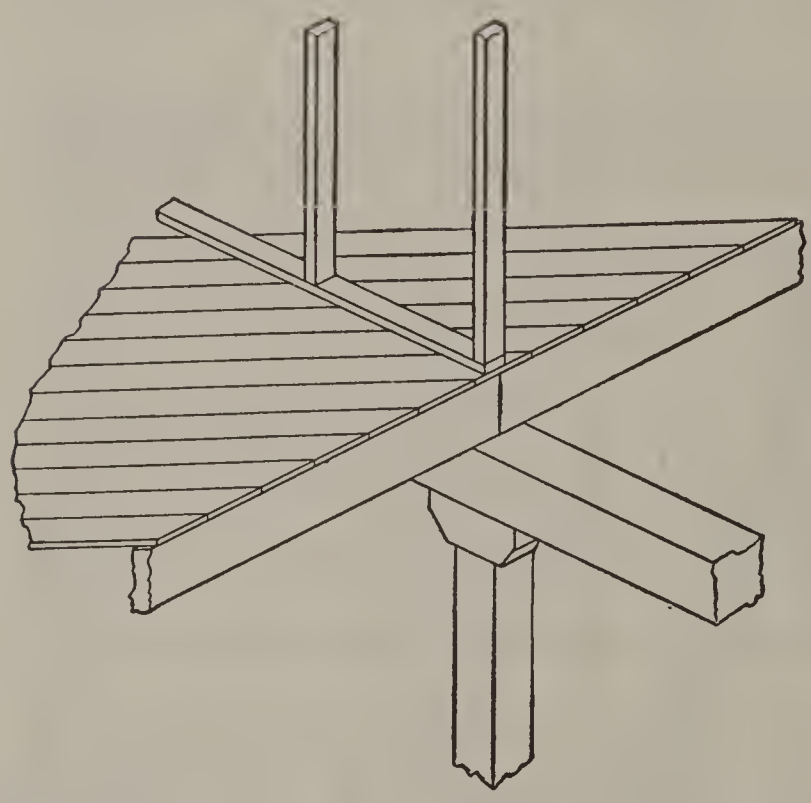


FIGURE 47.—Joists run over top of girder increase the vertical height of the wood used across the grain and increase subsequent shrinkage

Where structural lumber has a moisture content higher than that recommended, consideration should be given to the type of framing that will give best results. Construction methods that minimize the use of wood across the grain in vertical supports minimize shrinkage. For example, if joists are run over the top of a girder (fig. 47), the vertical height of wood used across the grain is great and opportunity for subsequent shrinkage may be proportionate. On the other hand, if the joists bear on ledger strips nailed to the sides of a girder (fig. 48), the vertical inches of side grain are reduced and possible shrinkage reduced accordingly. In this type of construction the joists may be notched over the nailing strip, or preferably the depth of the girder can be equal to the depth of joist plus the nailing strip. The use of metal post caps in preference to wood corbels carries out this same idea.

The platform type of construction (fig. 49) is intended to equalize but not to minimize shrinkage, and it accomplishes the purpose satisfactorily within the building even where the material used is only partially seasoned. However, the vertical shrinkage at the floor lines offers a problem difficult to overcome at chimneys and on outside walls where brick or stone veneer or stucco is carried up unbroken. Where the design calls for a break, such as overhanging second floor or a change in materials, provision for shrinkage is readily provided.

In the standard-balloon (fig. 50) and braced-frame (fig. 51) types of construction, vertical shrinkage in the exterior walls has been held to a minimum and this system is preferable where exterior walls are veneered or stuccoed without a break at the intervening floor line.

Interior bearing walls are either of the platform type or of the type where the first-floor studs extend to the basement girder and where possible the second-floor studs extend to the top of the first-floor partition cap. For one-story structures the platform system is preferable as it permits both the bearing walls and the nonbearing walls, which are supported by the joist to settle uniformly. For the same reason, the platform type may be used for the interior walls of the second floor in two-story structures having exterior walls of balloon- or braced-frame construction. Where the balloon or braced frame is used for exterior walls and platform construction for interior bearing walls, shrinkage at the interior walls of the first-floor structure plus that of the second-floor structure may be sufficient to cause plaster cracks and other evidence of shrinkage, particularly on the second-floor cross walls. Extending the bearing partition studs of the first floor down to the top of the basement girder reduces the shrinkage that causes plaster cracks on the second floor. This system, however, results in uneven shrinkage between the cross walls and the bearing partition on the first floor which may be sufficient to cause plaster cracks at the junction of such walls unless thoroughly seasoned material is used.

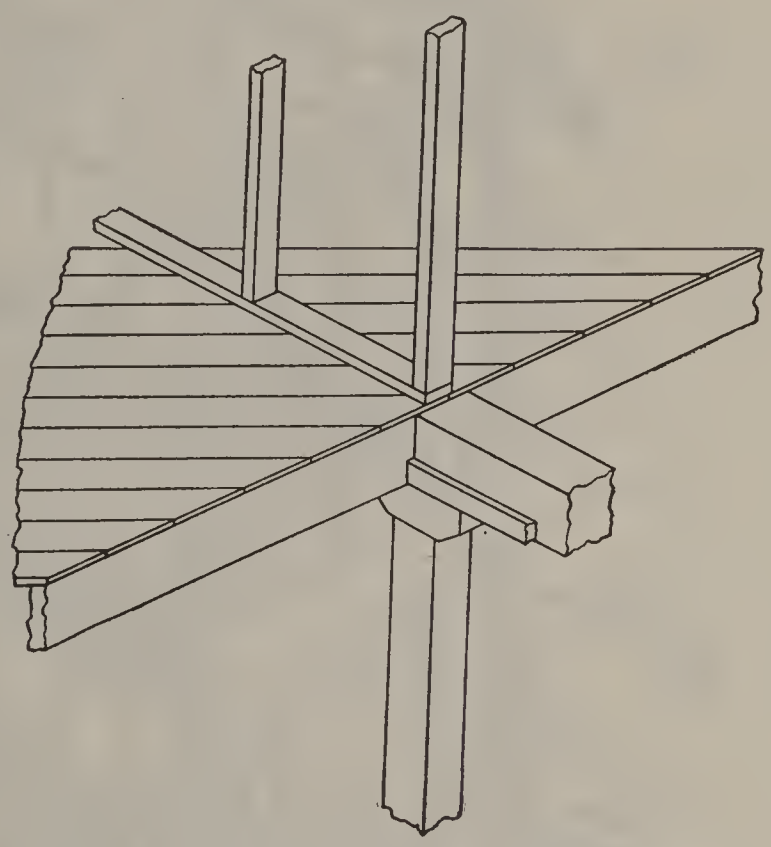


FIGURE 48.—Joists bear on ledger strips to minimize shrinkage

HEAVY TIMBER CONSTRUCTION

In heavy timber construction, a certain amount of shrinkage is to be expected (p. 193). If not provided for in the design, it may result in weakening of joints, affect floor levels, and be otherwise objectionable. One means of eliminating part of the shrinkage in mill buildings and similar structures is by use of metal post caps whereby the upper column is separated from the lower column only by the metal in the post cap. This method eliminates the shrinkage that would occur if the girder is used as a bearing for the upper column. The same thing is accomplished by the use of a cast-iron pintle resting upon a metal post cap over the top of the lower column to support the upper column, which also allows the girder to bear over the lower post (p. 215). The stem of the pintle, being encased, is protected from fire and as the girder bears over the column, the

cap is less likely to fail than where the girder is supported entirely by the cap.

Where joist hangers are used, the top of the joist, when installed, should be slightly above the top of the girder; otherwise when the joist shrinks in the stirrup, the floor will be higher over the girder

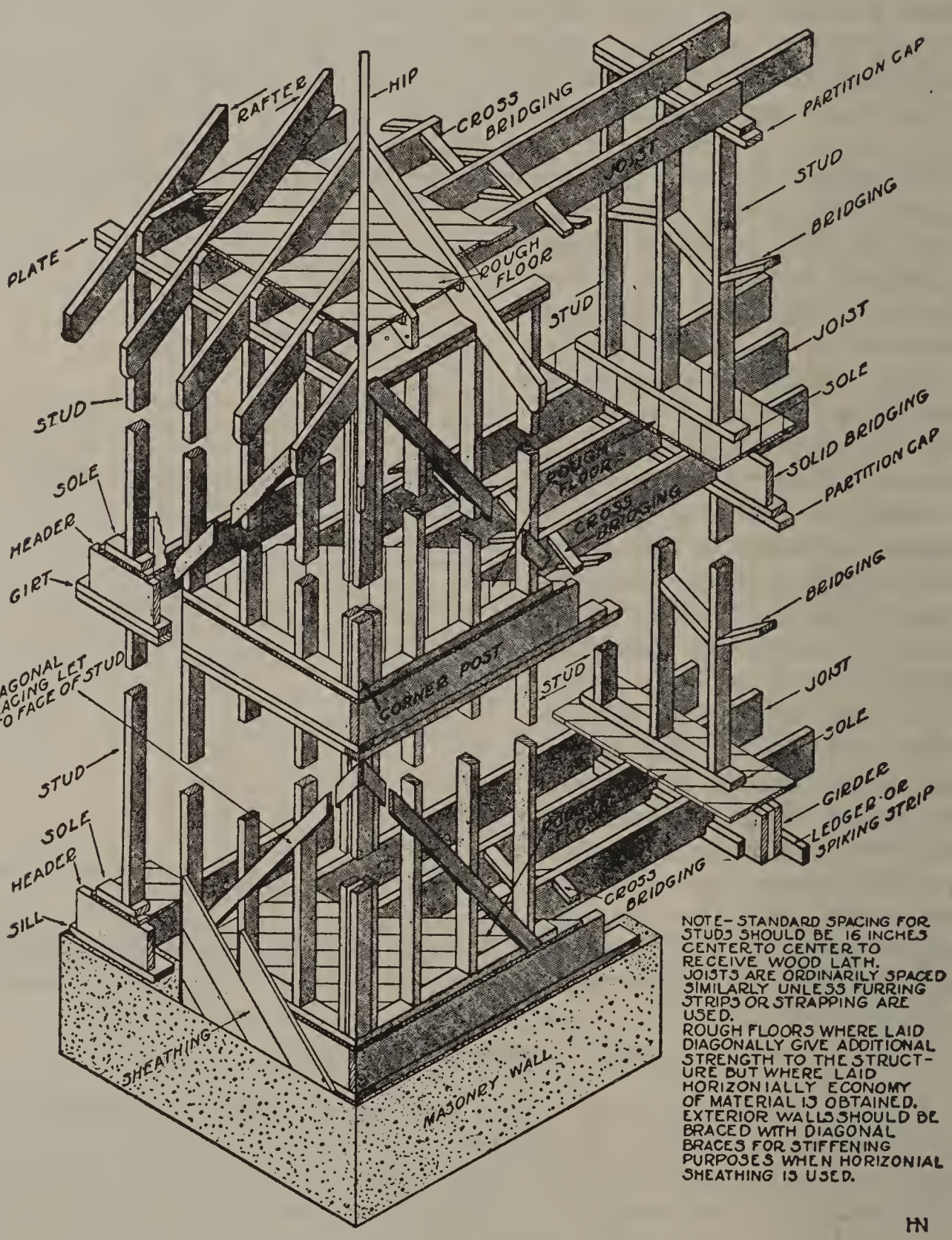


FIGURE 49.—Platform-frame construction.

than where it bears upon the joist. Laminated floor material can easily be properly seasoned and shrinkage minimized accordingly, because each piece is of relatively small cross section.

INTERIOR FINISH

The normal seasonal changes in the moisture content of interior finish are not enough to cause serious dimensional change if the stock is properly seasoned and the woodwork is carefully designed

and assembled (p. 192). Large members, such as ornamental beams, cornices, newel posts, stair stringers, and hand rails, should be built up from comparatively small pieces. Wide, plain surfaces, such as table tops, counter tops, and panels should be crossbanded, while door stiles and rails shold be laminated. Door and window trim

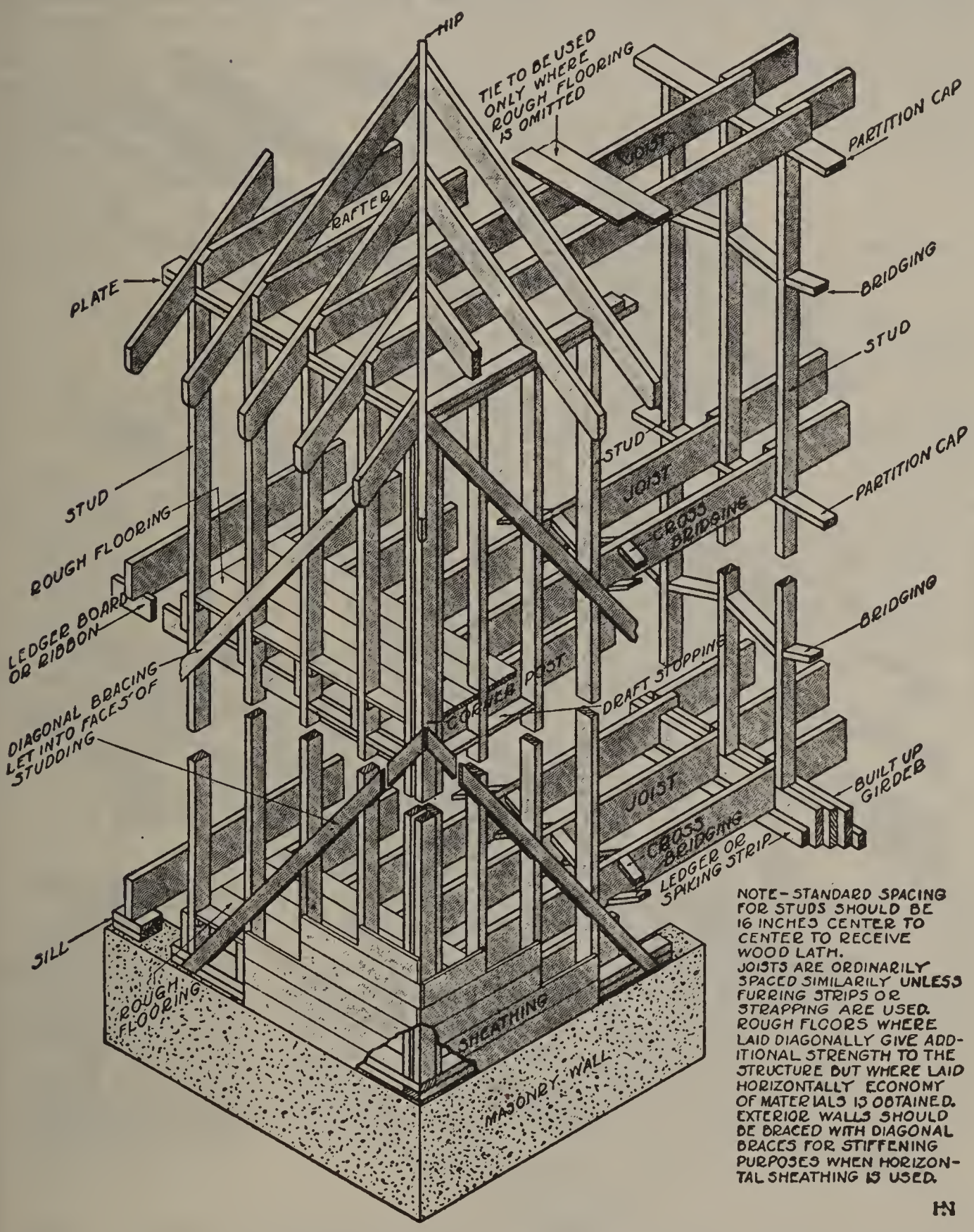


FIGURE 50.—Balloon-frame construction.

and base should be hollow backed. Backband trim, if mitered at the corners, should be glued and splined before erection, otherwise butt joints should be used for the wide faces. Large solid pieces, such as knotty-pine panels, should be stained and finished as much as possible before erection and should be so installed that the panels are free to move across the grain.

SEASONING OF LUMBER

MOISTURE IN WOOD

The moisture in wood, commonly called "sap", may for all practical purposes in the drying of wood (Mathewson and Thelen) be considered as water alone. Table 44 gives some moisture-content

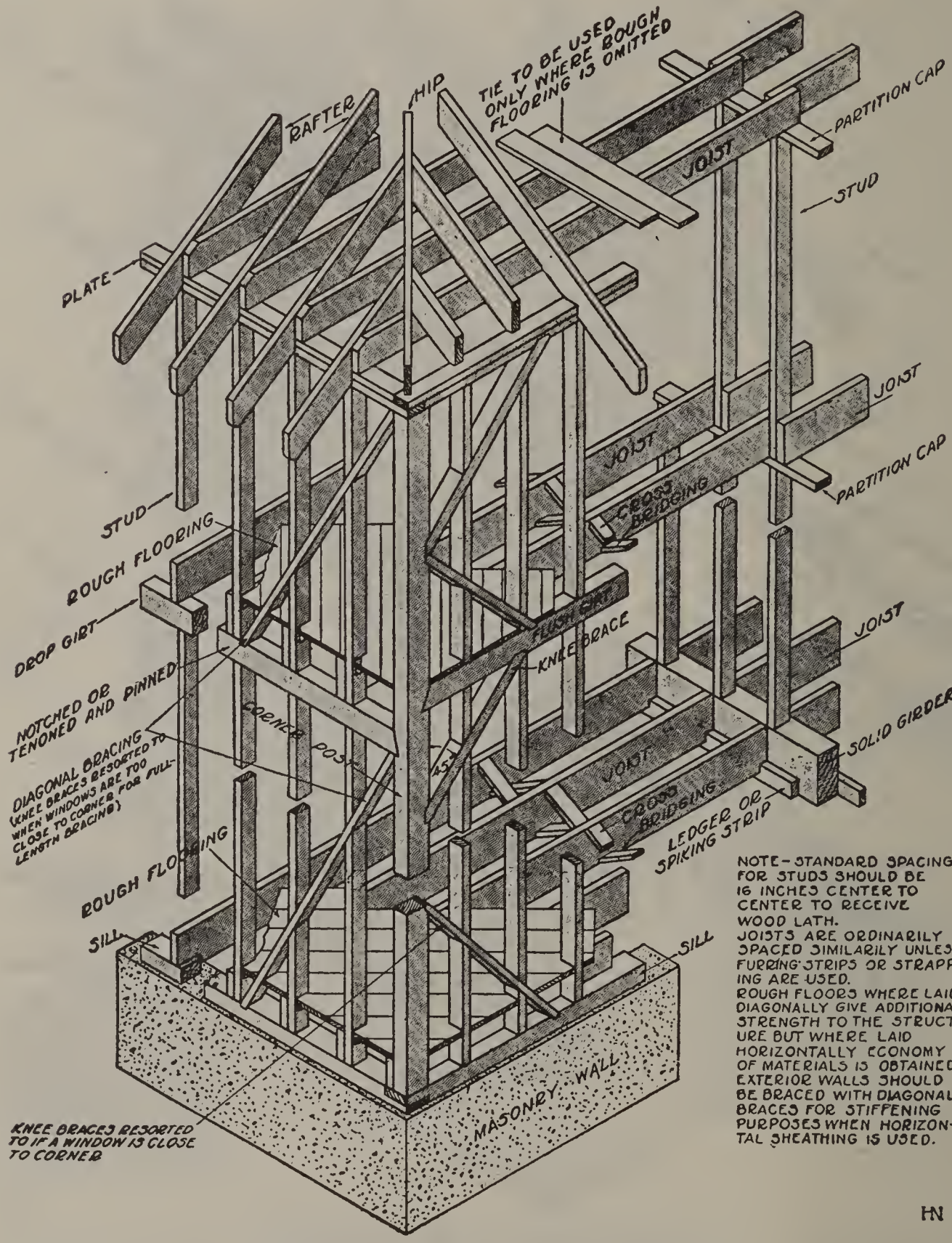


FIGURE 51.—Braced-frame construction.

values for green heartwood and sapwood of various species. The values shown may be considered average, and considerable variation from these values in individual trees and single boards may be expected, particularly in sapwood.

Sawmills cutting softwoods generally grade their products at the time of sawing. With few exceptions timbers, dimension, and low-

grade lumber are sent to the yard for air seasoning or are shipped green, whereas the upper grades intended for interior finish and flooring are kiln dried because of the use requirements. At certain mills some of the dimension and lower grades are partially kiln dried to hasten the seasoning process, to reduce the susceptibility to stain and decay, and to obtain the benefit of lowered freight charges. Sawmills cutting hardwoods commonly classify for size and grade at time of sawing and then send all stock to the air-seasoning yard. Ultimately, hardwood stock must be kiln dried before remanufacture, since it is used mostly where a relatively low moisture content is required, as in cabinetwork, interior finish, flooring, and furniture.

TABLE 44.—*Average moisture content for green heartwood and sapwood of 20 species*

Species	Average moisture content		Species	Average moisture content	
	Heartwood	Sapwood		Heartwood	Sapwood
Hardwoods:	*Percent*	*Percent*	Softwoods—Continued.	*Percent*	*Percent*
Ash, white	38	40	Pine:		
Beech	53	78	Loblolly	34	94
Birch, yellow	63	71	Lodgepole	36	113
Elm, American	95	92	Longleaf	34	99
Gum, black	50	61	Norway	31	135
Maple:			Ponderosa	40	148
Silver	60	88	Shortleaf	34	108
Sugar	58	67	Redwood	100	210
Softwoods:			Spruce:		
Douglas fir	36	117	Engelmann	54	167
Fir, lowland white	91	136	Sitka	33	146
Hemlock:					
Eastern	58	119			
Western	42	170			

AIR SEASONING

The principal advantages of air-seasoned over green wood (Mathewson; Teesdale, Circ. 421; and National Committee on Wood Utilization) are: Reduction in weight, with a resulting decrease in shipping costs; reduction in the shrinkage, checking, honeycombing, and warping occurring in service; decrease in the tendency for blue stain and for other forms of fungi to develop; reduction in liability to some forms of insect attack; increase in strength; and improvement in the capacity of the stock to hold paint or to receive preservative treatment.

KILN DRYING

Among the advantages over air seasoning that result from kiln drying (Teesdale, Tech. Bull. 165; Thelen, and National Committee on Wood Utilization) are the following: Greater reduction in weight, and consequently in shipping charges; reduction in moisture content to any desired value, which may be lower than that obtainable through air seasoning; reduction in drying time below that required in air seasoning; and the killing of any stain or decay fungi or insects that may be in the wood.

SEASONING DEFECTS

Material practically free of seasoning defects in the higher grade of lumber is insured by adherence to approved grading rules on the part of the manufacturer and knowledge of the material and its grades on the part of the user. Defects that sometimes develop in seasoning may be classified (Humphrey; Teesdale, Circ. 421, Tech. Bull. 165; and Thelen) into two main groups: (1) Those caused by uneven shrinkage which include checks, honeycomb, warp (cup, bow, crook, and twist, fig. 52), loosening of knots, and collapse, and (2) those caused by the action of fungi, which cause molds, stains, and decay. Chemical brown stain, frequently known as yard or kiln brown stain, may also occur in some softwoods. It is a yellow to dark-brown discoloration and is apparently caused by the oxidation of water-soluble materials in the wood.

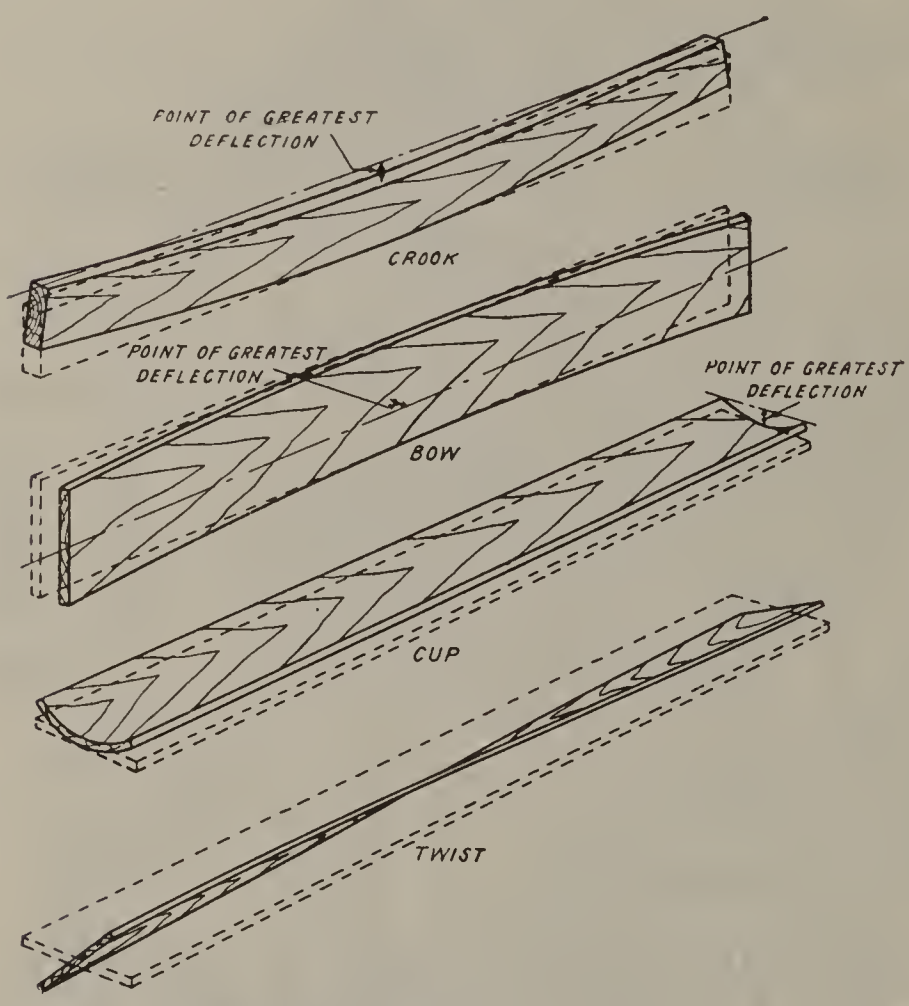


FIGURE 52.—Various kinds of warp.

The defects enumerated under (1) and (2) can be largely eliminated by proper practice in either air seasoning or kiln drying. Too rapid drying will cause such defects as checking, honeycombing, and warping, whereas too slow drying under favorable temperatures will cause stain or decay. When defects occur the amount permitted varies with the grade of lumber as specified in the grading rules of the various lumber associations. Most defects are specifically mentioned, but such defects as honeycombing and collapse are covered indirectly, as for example in softwood grading rules which state:

> When defects or blemishes not described in these grading rules are encountered, they shall be considered as equivalent to known defects according to their damaging effect upon the piece in the grade under consideration.

Honeycombing and collapse are more common in hardwoods than in softwoods and are more likely to occur during kiln drying than during air seasoning.

MOISTURE CONTENT OF SEASONED LUMBER

The trade terms "shipping-dry", "air-dry", and "kiln-dried", although widely used, have no specific or agreed meaning with respect to quantity of moisture. The wide limitations of these terms

as ordinarily used are covered in the following statements, which, however, are not to be construed as exact definitions:

Shipping-dry lumber.—Lumber that is partially air-dried to reduce freight charges and may have a moisture content of 30 percent or more.

Air-dry lumber.—Lumber that has been exposed to the air for any length of time. If exposed for a sufficient length of time it may have a moisture content ranging from 6 percent, as in summer in the arid Southwest, to 24 percent, as in the winter in the Pacific Northwest. For the United States as a whole the minimum moisture-content range of thoroughly air-dry lumber is 12 or 15 percent, and the average is somewhat higher.

Kiln-dried lumber.—Lumber that has been kiln-dried for any length of time. Properly kiln-dried lumber in the upper grade softwoods and upper and lower grade hardwoods intended for general use will ordinarily have a moisture content of 6 to 8 percent. Lower grade, kiln-dried softwood lumber is likely to have a moisture content of 15 to 22 percent.

Because the suitability of wood for certain purposes depends so much on the correct moisture content, specific values for the particular uses (p. 192) should be stated in the specifications. The importance of suitable moisture-content values is being recognized, and provisions covering them are now incorporated in some grading rules. It should be noted, however, that the moisture-content values in the general grading rules may or may not be suitable for a specific use, and if not, a special moisture-content provision should be made in the specifications.

STORAGE OF LUMBER AT YARDS

When received at a distributor's lumber yard lumber may be practically green, partially seasoned, or thoroughly seasoned. If green or partially seasoned the stock should be open piled on stickers and covered with a rainproof roof (Mathewson, and National Committee on Wood Utilization). If seasoned to a moisture content of less than 20 percent it is good practice to solid pile it in a shed that will afford ample protection against rain and wind.

Lumber that has a moisture content higher than 20 percent is likely to become stained or decayed when piled solidly. On the other hand, lumber, even though at a moisture content of less than 20 percent, when not properly protected against the weather is apt to stain or decay. Furthermore, an undesirable increase in dimensions and moisture content may occur that subsequently results in objectionable shrinkage of the lumber in service.

The foregoing relates primarily to such items as shiplap, studs, and joists. With flooring and interior trim, it is advisable to provide heated storage during damp weather in order to maintain the lumber at the desired moisture content.

To determine what temperature should be maintained within the storage shed in a given case consult figure 53. For example, if the outdoor temperature is 30° F., the relative humidity 80 percent, and the desired equilibrium moisture content is 8 percent, proceed as follows: From the intersection of the (vertical) 30°-temperature line

and the (horizontal) 80-percent relative-humidity line, extend a line midway between the adjacent (concave) vapor-pressure lines until it intersects a line midway between the 7- and 9-percent moisture-content lines indicated on the right-hand ordinate. The reading on the bottom scale at the point of the second intersection is about 47°. In other words, under the conditions stated, the moisture content of the flooring can be maintained merely by heating the air to 47°.

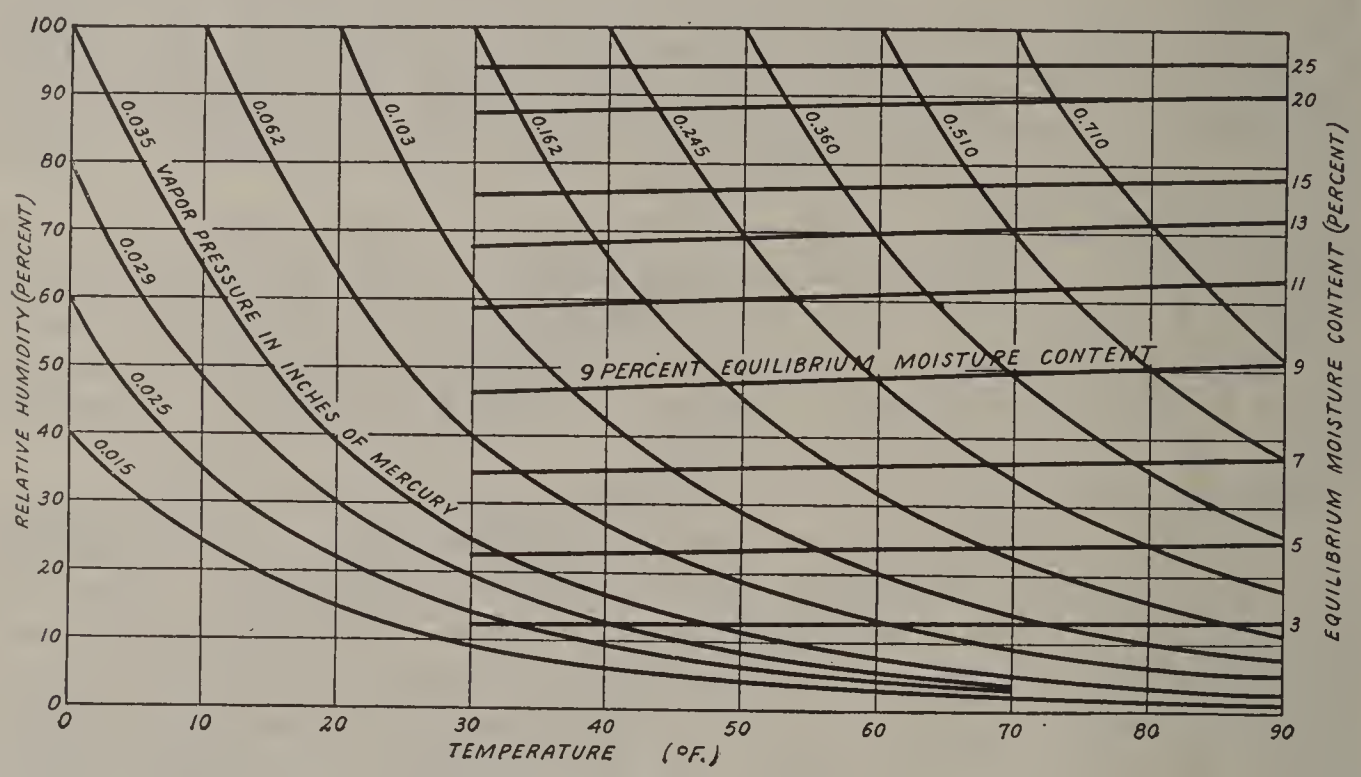


FIGURE 53.—Relationship of relative humidity, vapor pressure, equilibrium moisture content, and temperature.

CARE OF LUMBER AND FINISH DURING CONSTRUCTION

LUMBER

Ordinarily green lumber should not be used in the construction of a building. A simple means of protecting dry lumber awaiting use on a building site is to pile it solidly on three timbers and to cover at least the top and ends with a tough, moisture-retardant building paper. The tendency for the paper to tear as a result of shrinkage can be considerably reduced by tacking lath to the ends of the paper and holding the lath tight against the ends of the pile by several stakes driven firmly into the ground rather than tacking the lath directly to the pile. Unless the top, sides, and ends of the pile are protected during rainy weather, the boards should be separated by stickers; lath spaced about 4 feet apart along the length of 1-inch boards is satisfactory. With thicker stock the use of stickers is not so important.

Shortly after use for concrete forms lumber should be properly piled and protected from rain and sunshine so as to dry and remain straight and free from checks before subsequent use in the building.

The statements concerning damage due to lack of proper protection during storage in lumber yards are, of course, applicable in the present instance. In addition, the top layers of piles exposed to the sun and rain are subject to warping and checking.

Frequently in the construction of houses, the garage, if detached, may be built first and may serve as an excellent storage space for sheathing, siding, studs, and joists.

FINISH FLOOR

The absorption by flooring of moisture from the air within the building either before or after the flooring is laid and the resulting swelling followed by shrinkage when the building is heated is largely responsible for cracks in floors (Teesdale, Leaflet 56). Such cracks can be greatly reduced if not entirely eliminated by observing the following practices: Specify flooring manufactured according to association rules and sold by dealers that protect it properly while in their hands; do not allow the flooring to be delivered on a damp or rainy day or before the masonry and plaster walls are dry; eliminate all badly crooked pieces or use them in inconspicuous places; maintain heat in the building as recommended under interior finish.

Better and smoother sanding and finishing can be done when the house is warm and the wood has been kept dry. One approximate method of determining whether the air in a building is dry enough to permit of the delivery and installation of flooring and other interior woodwork is to take two readings on a wet- and dry-bulb hygrometer on each of several days. These readings are best taken near the floor and walls at 7 a. m. and 5 p. m. The corresponding relative-humidity values should be averaged. If in comparing the average thus obtained with the corresponding equilibrium moisture content as obtained on page 205 the latter is found to be about 8 percent, it may be assumed that the atmosphere within the building is dry enough to have the woodwork delivered and installed. The correct equilibrium-moisture content conditions should then be maintained until the building is occupied.

INTERIOR FINISH

In a building under construction the relative humidity will average higher than it will in an occupied house because some moisture is available for evaporation in new concrete, brickwork, plaster, and even in the structural-wood members. The average temperature will also be lower because workmen prefer a lower temperature than is agreeable in an occupied house. Under such conditions the tendency of the finish is to have a higher moisture content during construction than it would have later during occupancy.

Before any interior finish is delivered, the outside doors and windows should be hung and in place so that they may be kept closed at night and in this way hold the temperature of the interior as close as possible to the higher temperature and lower humidity that ordinarily prevails during the day. Such protection may be sufficient during the dry summer weather but during damp or cool weather it is highly desirable that some heat be maintained in the house, particularly at night (Teesdale, leaflet 56). Whenever possible the heating plant should be placed in the house before the interior trim goes in, in which event it will be available as a means of supplying the necessary heat. Portable heaters may be used and are inexpensive to operate. The temperatures during the night should be maintained at about 15° F. above outside temperatures and not allowed to drop below about 70° during the summer or 62° to 65° when outside temperatures are below freezing. After buildings have thoroughly dried there is less need for heat, but unoccupied houses,

new or old, should not be allowed to stand without some heat during the winter. A temperature of about 15° above outside temperatures and above freezing at all times will be sufficient to keep the woodwork, finish, and other parts of the house from being affected by dampness or frost.

PLASTERING

During the plastering operation in a moderate-sized six-room house approximately 1,000 gallons of water are used, all of which must be evaporated before the house is ready for the interior finish. Failure to provide adequate ventilation to secure removal of evaporated moisture means trouble later because of the moisture absorbed by the framework. It is also a cause of paint blistering on exterior finish and siding. During warm dry summer weather with the windows wide open this moisture is practically gone within a week after the final coat of plaster is applied. During damp, cold weather drying is retarded accordingly. Adequate ventilation should be provided at all times of the year, as the evaporated moisture is air borne and a large volume of air is required to carry away the amount of water involved.

When the heating system or portable heaters are used to prevent freezing of plaster and to hasten its drying the windows should be properly adjusted to allow the escape of the evaporated moisture. Even in the coldest weather the windows on the leeward side of the house should be opened 2 or 3 inches, preferably from the top.

DETERMINATION OF MOISTURE CONTENT

The amount of moisture in wood is ordinarily expressed as a percentage of the weight of the wood when oven dry. The four distinct methods of determining moisture content are described below. The oven-drying method is probably the most exact but is slow and necessitates mutilation of the wood; the distillation method is necessary if the wood contains creosote or other volatile oils; the electrical method is the most rapid and also does not necessitate cutting the material; the wood hygrometer gives fairly quick results, and the apparatus, if commercially manufactured, should be inexpensive.

OVEN-DRYING METHOD

In the oven-drying method (Thelen), samples about 1 inch long in the direction of the grain are cut from representative boards of a lot of lumber. These samples should be at least 1 foot from the end of the boards to avoid the effect of end drying and should also be free from knots and other defects.

Each sample is immediately weighed, before any drying has taken place, and is then placed in an oven heated to 212° F., and kept there until of constant weight. The difference between the original and the oven-dry weight divided by the oven-dry weight, multiplied by 100, is the percentage of moisture based on the dry weight.

For weighing ordinary moisture-determination sections, balances having a capacity of about 200 grams and sensitive to 0.1 gram are recommended. For weighing larger samples or whole boards a platform scale having a capacity of 100 pounds or more and sensitive to 0.01 pound is satisfactory.

Both steam and electric ovens are in common use for drying moisture-determination sections. The sections, with either type of oven, should be open piled in order to permit good circulation of air, especially around the end grain of each piece, to hasten drying.

DISTILLATION METHOD

When it is necessary to determine the moisture content of a sample of wood which contains a considerable quantity of volatile oils, oil preservatives, or any other material part of which might be lost by heating, the distillation method should be used (American Society for Testing Materials).

In this method a 100-gram sample of wood in the form of chips, borings, or sawdust is immersed in some water-insoluble oil of low density such as kerosene or xylol in a flask which can be heated by suitable means and is provided with a reflux condenser discharging into a trap connected to the flask. The trap serves to collect and measure the condensed water and to return the solvent to the flask. The distillation is continued until no more water is obtained in the distillate. The volume of water in the sample is obtained by direct reading.

Since moisture content is expressed in terms of the oven-dry weight of the oil-free wood, any oil preservative, such as creosote, which the sample may contain must be extracted in order that this weight may be determined. This can be done by carefully transferring the sample or another aliquot to an extraction thimble, placing it in a Soxhlet extractor and extracting it with a suitable solvent. In addition to the oil preservative, various oil-soluble constituents of the natural wood will be removed by the solvent. After extraction the extracted sample is oven dried to constant weight at 105° C. (221° F.). The moisture content is then calculated on the basis of the dry, oil-free wood.

ELECTRICAL-RESISTANCE METHOD

Where the rapid indication of the moisture content of wood is desired, as for inspection purposes, the electrical-resistance method is the most suitable (Suits and Dunlap). This method is based upon the well-known fact that the electrical resistance of wood changes with moisture content. Several types of portable electrical moisture instruments are now on the market. The features common to the instruments are two pairs of sharp metallic terminals that can be quickly embedded in the wood, batteries for supplying an electric current through the wood intervening between the two terminals, and a means for reading the resistance in the electric circuit directly in terms of the moisture content of the wood holding the terminals. Different species of wood vary in their electrical resistance for a given moisture content (p. 43), and this fact must be taken into consideration in making moisture determinations. Manufacturers usually supply proper correction factors. The range of the present instruments is about 7- to 24-percent moisture content.

The electrical-resistance method has an advantage over the oven-drying method principally on account of its speed and convenience, the time required to determine the amount of moisture in any piece

of wood being only a few seconds. It is therefore very adaptable for sorting lumber on the basis of its moisture content. The moisture determination is usually made on the back of the piece somewhere near the center. This procedure avoids marring the face when the metallic terminal points are inserted. The electrical methods are the only practical means thus far developed by which the moisture content of finished woodwork in place can be determined without serious injury to the wood.

Some judgment must be exercised in the use of electrical moisture meters, because those so far developed are designed for use on wood approximately 1 inch in thickness or on thicker material that is known to be uniform in moisture content. The critical measurement is made by the pair of electrodes in the driest wood, hence if the timber is much thicker than 1 inch and a moisture gradient is present in the wood an error may result because the needles will not be long enough to reach the wetter portions of the material. When a drying gradient exists an idea of the average moisture content can be obtained by inserting points to about one-fifth of the thickness of the material. An approximation of the highest moisture content in a timber can be obtained by driving long electrodes to the center of the piece. Electrical meters should not be used on lumber that has been recently wet by rainfall, as a surface film of moisture may indicate too high a moisture content.

WOOD-HYGROMETER METHOD

The relationship between the moisture content of wood and the relative humidity of surrounding air makes possible the use of a wood hygrometer for measuring such moisture content. It is much more rapid than the oven-drying method but not so fast as the electrical. Measurements can be made as low as 2-percent moisture content and up to 25 percent, although the accuracy decreases above 15 percent.

The instrument, which can be carried in the pocket, consists of a capillary tube containing mercury and closed at the bottom with a bulb of goldbeater's skin. Changes in relative humidity cause the bulb to change its area and so force the mercury up or down the tube in a manner similar to that of a thermometer. Thus when the instrument base encasing the bulb is fitted closely into a freshly drilled hole and left there for approximately 10 minutes, the relative humidity within the opening is registered on the graduated capillary tube in terms of the moisture content of the surrounding wood. The apparatus is fragile and has not been developed commercially.

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FIRE RESISTANCE OF WOOD CONSTRUCTION

The fire resistance of wood construction depends very largely upon the general type of construction and to a considerable degree upon the construction details employed in each particular type. It is also influenced by the use of protective devices, fire-resistant coverings, fire-retardant coatings, and impregnation of the wood with fire retardants.

INCREASING FIRE RESISTANCE OF WOOD CONSTRUCTION THROUGH DESIGN

General principles of design for fire prevention and control, as they affect two major divisions of wood construction, namely, slow-burning, or heavy-timber construction (Dean; Holtman, pp. 439–465; Insurance Engineering Experiment Station; Jacoby and Davis; pp. 245–252; National Board of Fire Underwriters; National Fire Protection Association; National Lumber Manufacturers' Association; and Stradling, pp. 854–897)[33] and light construction (U. S. Federal Board for Vocational Education, Ingberg, National Board of Fire Underwriters, U. S. Department of Agriculture Farmers' Bull. 1590, and Bureau of Standards Building and Housing 14 and 18) are presented here.

SLOW-BURNING HEAVY-TIMBER CONSTRUCTION

The slow-burning heavy-timber construction, which is also known as mill-type construction, was perfected in New England and has been used generally in manufacturing centers throughout the United States. This type of construction under automatic sprinkler protection compares favorably with so-called "fireproof construction" in terms of performance standards and consequently enjoys favorable insurance rates. It may be erected rapidly and is easy to repair or remodel to suit changing conditions.

Essentially, slow-burning heavy-timber construction consists of exterior walls of masonry with interior framing and floors of timber and plank in heavy solid masses having a minimum of surface and projections exposed to fire, so arranged that all parts can be easily reached by sprinklers or swept by hose streams. In addition, all openings between floors are enclosed with fire-resistive partitions and walls; doors and hatchways are automatically closed in case of fire; ceilings over hazardous stock or processes of manufacture are protected with fire-retardant material, and all reasonable precautions are taken to avoid rapid spread of fire. Minimum thicknesses of floors and sizes of beams and columns are established in building codes governing this type of construction.

Two general classes of interior framing of slow-burning construction are now accepted practice; namely, standard mill construction and semimill construction.

[33] For further information, the references at the end of this section should be consulted.

In the standard mill, or girder type of heavy-timber construction, floors of heavy plank are laid flat upon large timber girders, which are usually spaced not less than 8 feet apart. The columns supporting the girders are commonly spaced about 20 feet apart making a bay about 8 by 20 feet. This type, which permits a maximum spacing of about 12 feet between girders, is less desirable than it was formerly because of the demand for larger clear spaces.

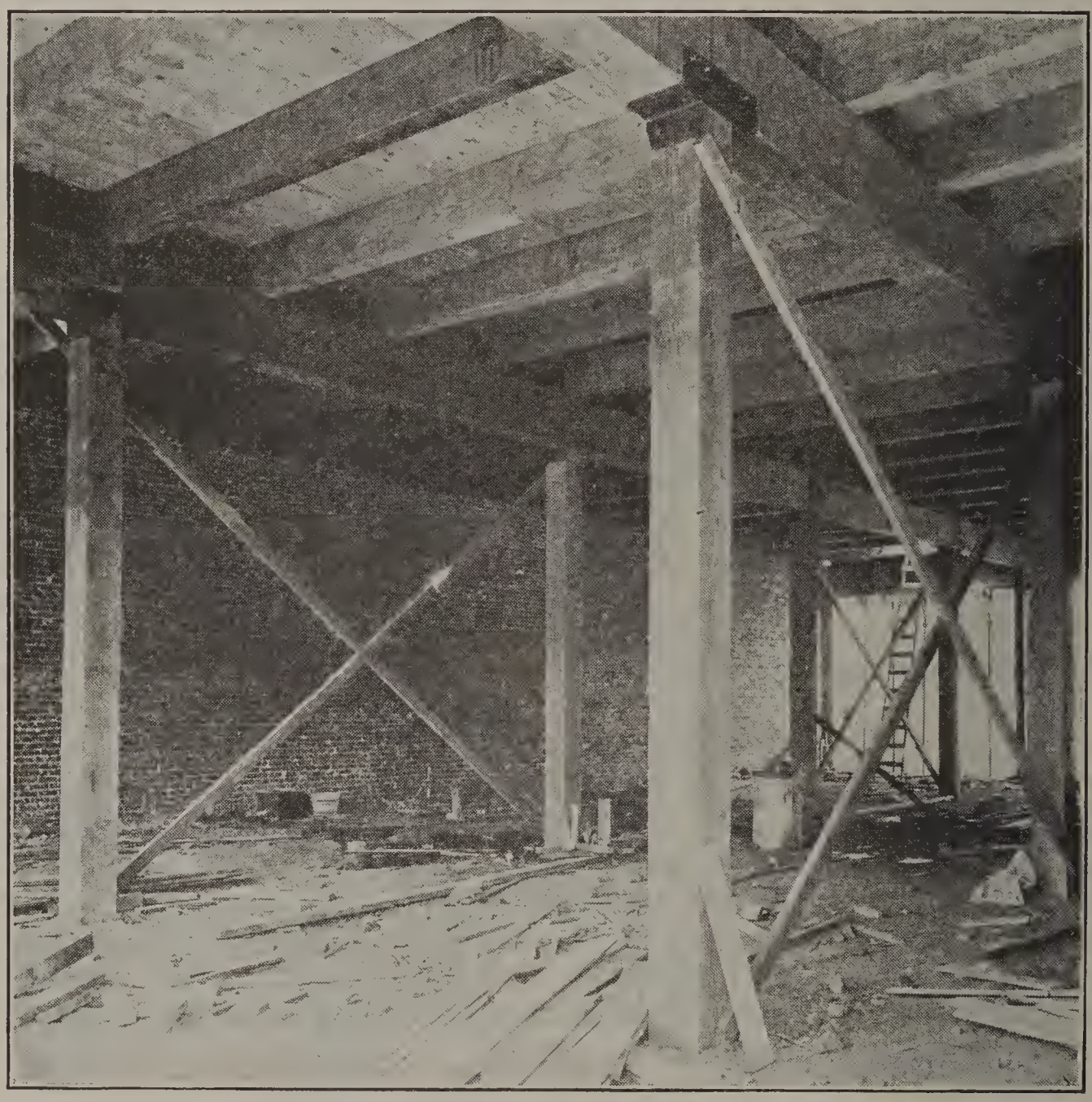


FIGURE 54.—Beam-and-girder type of heavy-timber construction.

Laminated floors consisting of planks laid on edge are sometimes used in standard mill construction, giving wider bays and a stiffer floor; that is, the use of such floors permits of heavier loading and wider spaces between girders and columns.

In the semimill, or beam-and-girder type of heavy-timber construction (fig. 54), the timber beams are spaced not less than 4 feet apart and are supported by timber girders spaced as far apart as the floor loads will permit. The girders, in turn, are supported by wooden columns spaced as far apart as good design permits. The floors are of heavy planking laid flat.

With the beam-and-girder type the bays are more nearly square rather than, say, 8 by 20 feet or 12 by 20 feet. The beams either rest directly upon the girders or are suspended from the girders

by hangers. When suspended by hangers, or stirrups, the fire hazard is greater because fire may then burn off the ends of the beams more quickly, or the hangers, softened by heat, may give way and allow the beams to fall. From the standpoint of fire resistance, placing beams directly on top of the girders is preferable, although it requires more headroom for each floor.

Construction Details Contributing to Fire Resistance in Heavy-Timber Construction

PINTLES

A pintle (fig. 55) is a short cast-iron column with suitable top and bottom plates, used at the junction of wooden beams and columns (Stradling). Because cast iron is of high compressive strength the pintle may be of small diameter, thus requiring only a small hole through the beams, half of which is in each beam at the junction end. Since pintles are entirely surrounded by a heavy thickness of wood, except at the edges of the top and bottom plates, they are more protected against fire than many other forms of fasteners.

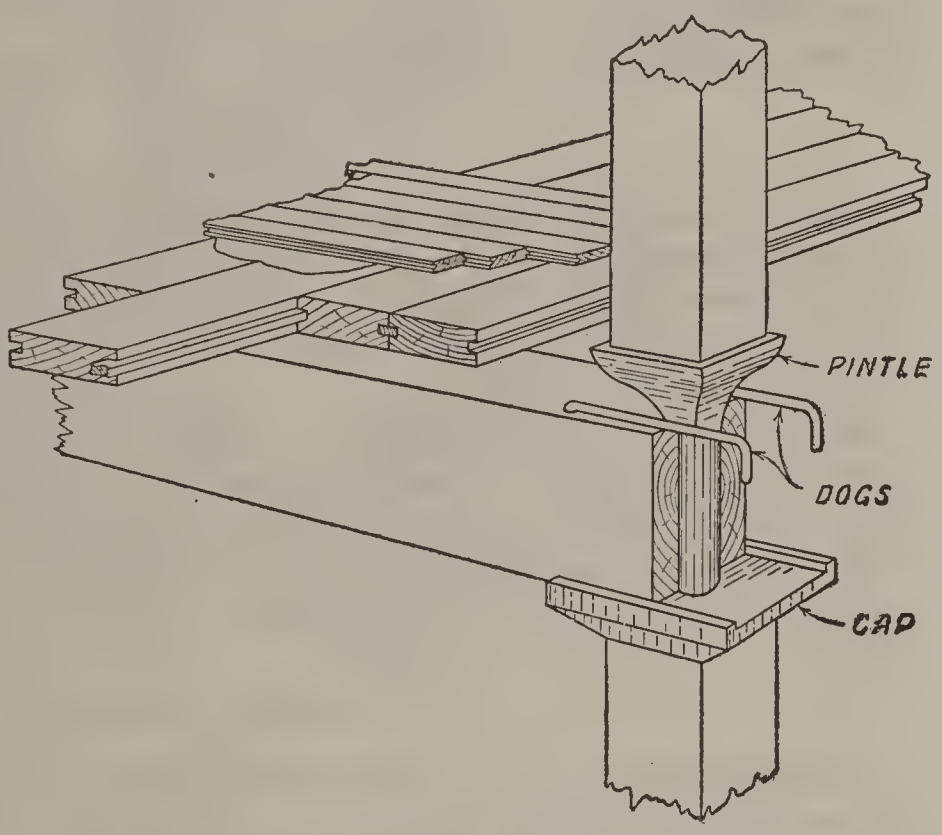


Figure 55.—Metal-post cap and pintle.

In addition, when pintles are used the columns virtually rest on each other, end to end, thus eliminating the settling that occurs because of shrinkage of the beams when the columns of one story rest on beams supported by the columns below. Also adjoining beams butt against each other, with their ends over the body of the column, and so have better support than that given by the overhanging ends of the column cap. Thus, if a cap end is burned or broken off, the beam support is not greatly affected. In addition, beams butted end to end form struts from one side of the building to the other and when they are fastened with metal dogs they also form continuous ties.

SURFACES

In slow-burning heavy-timber construction the aim is to obtain the necessary amount of strength with the minimum amount of surface and number of projections exposed (Holtman and Insurance Engineering Experiment Station). This is accomplished primarily by heavy, smooth floors and large structural members. A smooth surface does not ignite readily, and large timbers can withstand fire

for a considerable period before failure. Unprotected steel columns will give way long before a heavy wooden column (Ingberg, Griffin, Robinson, and Wilson).

BEAMS

Double beams with an air space between them are undesirable from a fire-hazard standpoint, because the space between them is shielded from sprinkler water and may burn sufficiently to cause failure.

FLOORS

The main or strength-giving floor should be at least 3 inches thick, nominal dimension, when laid flat on beams or girders. This floor should be splined. The top or finish floor is usually about 1 inch thick. Some of the better buildings have a double top floor; the intermediate floor is usually of a poorer grade of softwood laid diagonally. The diagonal floor is excellent for bracing, reduces vibration, and also helps distribute the load.

ROOFS

Roof planking is usually the same as floor planking and is laid in the same manner. Two and one-half inches is the usual minimum thickness of roofing plank; 3 inches is the common thickness. Hollow spaces that cannot be reached by sprinklers should be avoided in roof construction.

Wood trusses have good fire resistance if all members are of sufficient size. If all members are at least 4 by 4 inches, wood trusses will resist fire as well as exposed steel trusses (Bureau Standards, first reference), and if at least 6 by 6 inches they will be superior to exposed steel trusses (American Factory Mutual Fire Insurance Co.).

STAIRWAYS AND ELEVATORS

All stairways and elevator shafts should be entirely separated from the remainder of the building by fireproof walls. Doors leading to stairways or elevator shafts should close automatically.

DECAY

Adequate precautions must be taken against decay, because decayed wood ignites more readily than sound wood, and because the margin of safety in a structural member may be reduced by decay to such an extent that there will be but little reserve left to resist fire.

LIGHT CONSTRUCTION

Fire Stops

Fire stops are obstructions provided in concealed air spaces and are designed to interfere with the passage of flames up or across a building. Fire in buildings spreads by the movement of high-temperature air and gases through every open channel. In addition to halls, stairways, and other large spaces, these heated gases also follow the concealed spaces between floor joists, between studs in partitions and walls of frame construction, and between the plaster and the wall where the former is carried on furring strips. In a

dwelling or even in a large building where these hidden channels are not obstructed at suitable points, a fire may quickly find its way through them to all parts of the structure.

Fire stops are relatively inexpensive to install but are often overlooked in light construction. A well-fitted board will make a good fire stop, although fire stops should preferably be of incombustible material. The incombustible material should fill completely the spaces in walls and partitions opposite hollow spaces in floors, and for 4 inches or more above them. Incombustible materials suitable for fire stopping are concrete, plaster, mortar, cinders, hollow

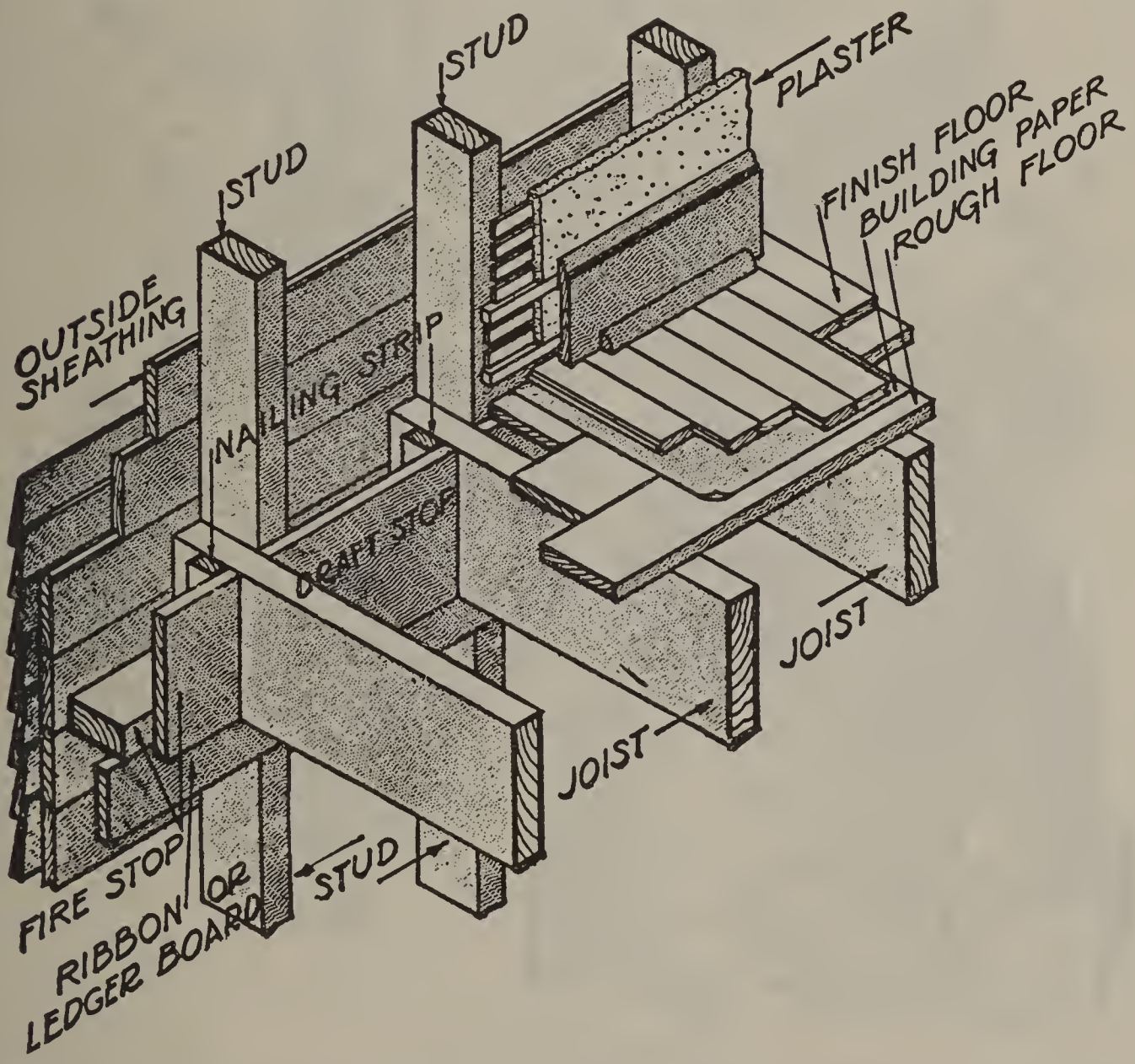


FIGURE 56.—Fire stopping in balloon-frame construction. This might be modified by omitting the ribbon and letting the 2 by 4 stop be continuous in the nature of a plate.

tile, brick, gypsum block, and mineral wool. To support this material, horizontal wood strips 2 inches thick beneath the filling and 1-inch horizontal boards on edge opposite the hollow floor spaces may be used. Metal lath or similar material also furnishes a good support for the fire-stopping material.

Methods of fire stopping at certain critical points in light construction are shown in figures 56 to 61.

FIREPLACES

Fireplaces (Farmers' Bull. 1590) are perfectly safe if properly built, but are a distinct hazard unless proper precautions are taken. It is too common practice when fireplaces are built against interior

partitions to place wooden furring strips directly on the brick backing of the fireplace preparatory to lathing and plastering. Furring strips so placed may be ignited through conduction of heat from the fireplace and spread fire within the walls. All furring strips, wooden beams, joists, or partition members should be placed 2 inches or more away from masonry work of fireplaces and the resulting space should be filled with an incombustible material.

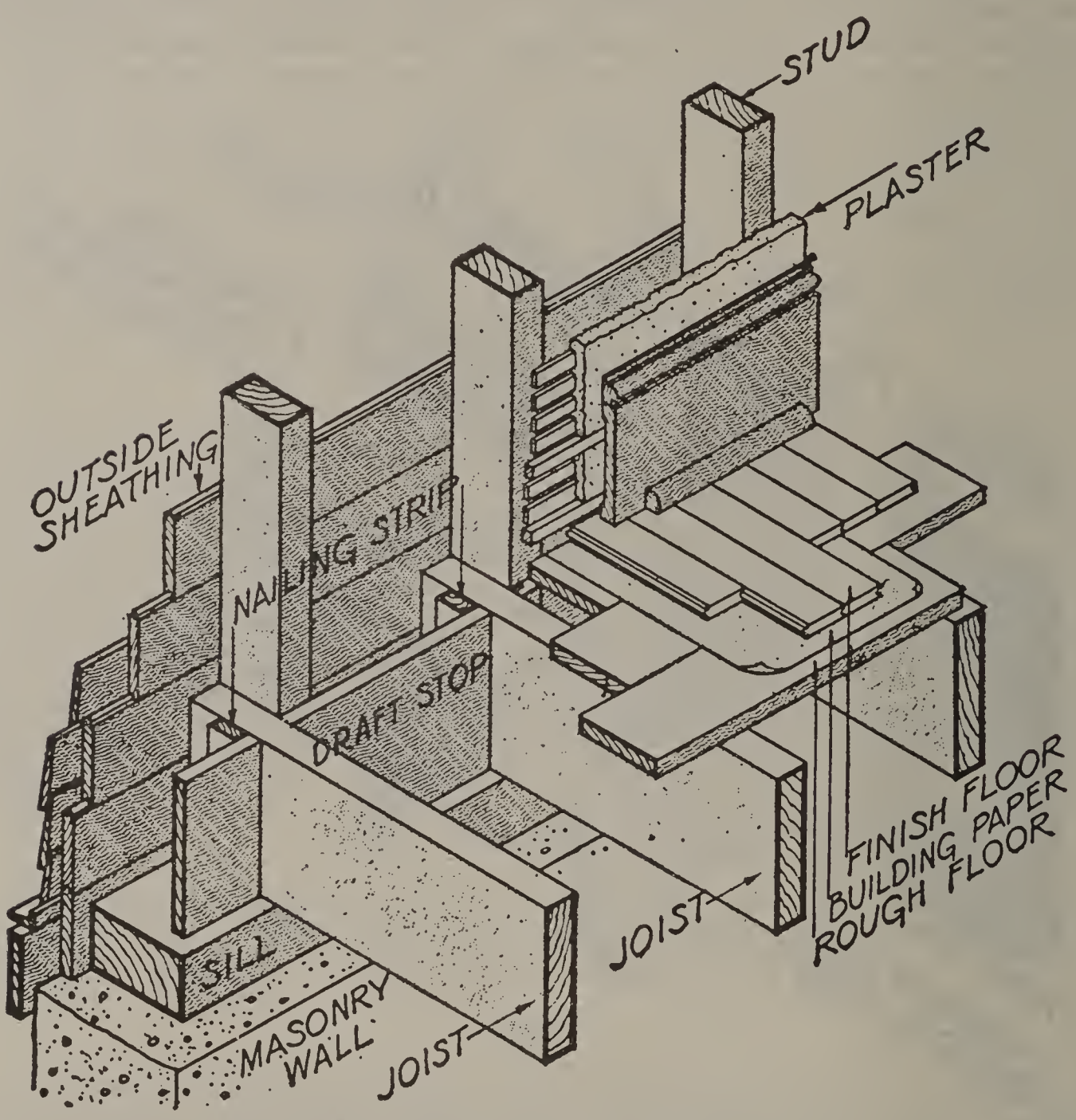


FIGURE 57.—A method of fire stopping at a sill.

CHIMNEYS

Properly built chimneys are a relatively low fire hazard. Brick chimneys that are improperly built, however, are a common source of fire because the ascending hot gases are likely to cause the mortar in the joints to disintegrate so that in time hot gases and flames may reach and ultimately ignite any adjacent wood. Flue lining should, therefore, always be used, and the space between the flue lining and the brick chimney wall should also be filled with portland cement or cement-lime mortar for the full length of the chimney. Then if the lining should crack, as it sometimes does under intense heat, it will remain in place and continue to function.

Only one connection to a flue should be made. Otherwise, the draft is impaired for one thing, and in addition there is danger, where only one connection is in active use, that an unused opening will communicate fire to connecting rooms. Such unused connections also accumulate soot, which in time may burn and produce a fire hazard.

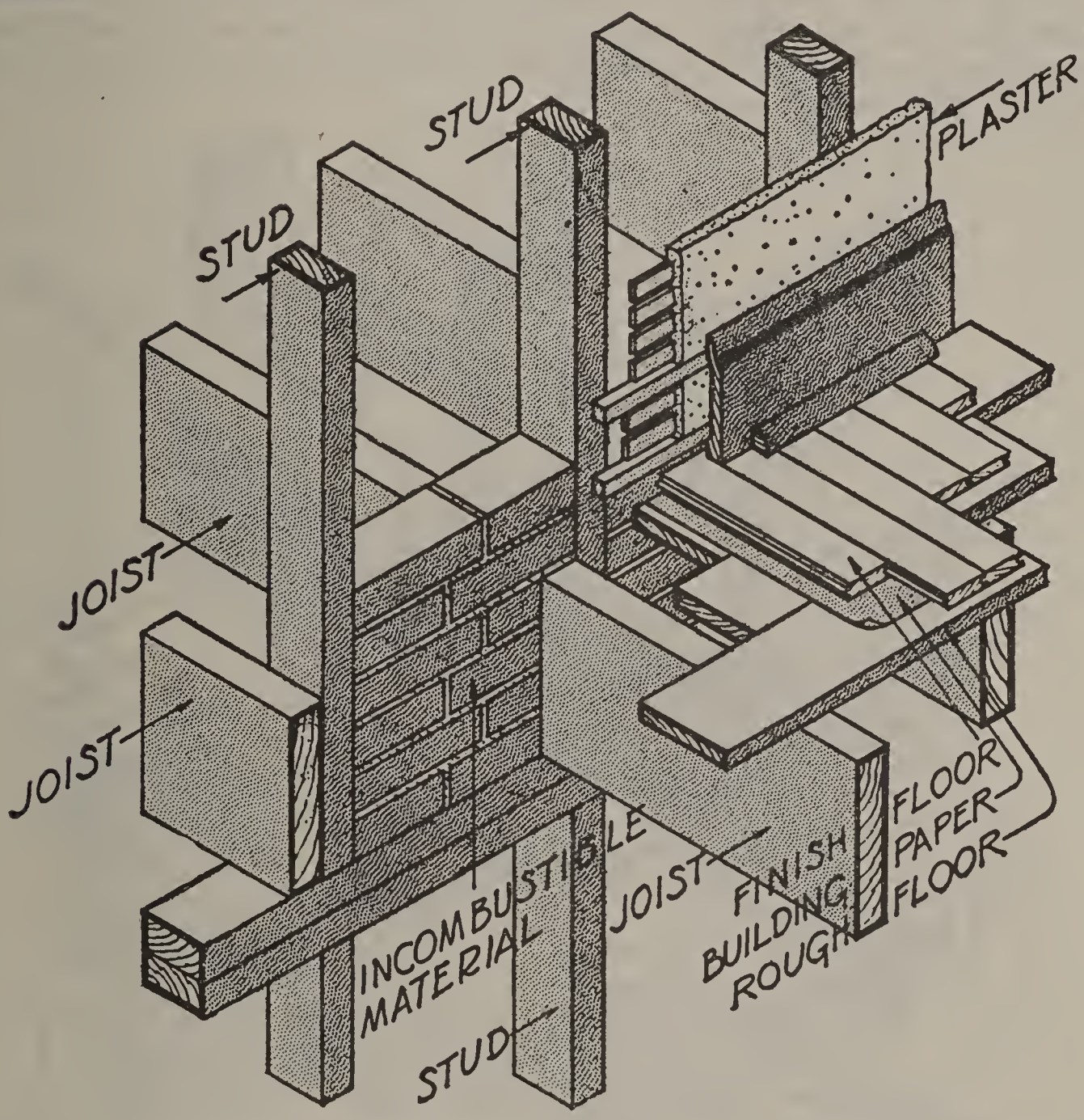


FIGURE 58.—One method of fire stopping at partitions.

BASEMENT CEILINGS

Primarily on account of the location of heating plants, many fires start in the basement and consequently it is desirable that a fire-resistant separation from the remainder of the structure be provided (Ingberg). Either gypsum board, asbestos board, or plaster on metal or wire lath placed on the basement joists afford an effective means of retarding the rapid spread of flames, but such material is usually omitted to reduce cost. Particular attention should be given to the wooden floor members directly above and near the furnace. The smoke flue should slope upward from the furnace to the chimney and should be at least 18 inches below the floor joists at all points.

If, as is common, a basement stairs is directly under the stairway leading from the first to the second floor, the under side of the latter

should be plastered, preferably on metal lath, and fire-stopped between the wooden carriages at the top and bottom.

Doors and Stairways

If a fire-resistant basement ceiling is built, a fire-resistant door leading to the basement is equally advisable. For other interior openings and with usual construction there is not much advantage in giving greater protection than that provided by an ordinary flush wooden door and frame.

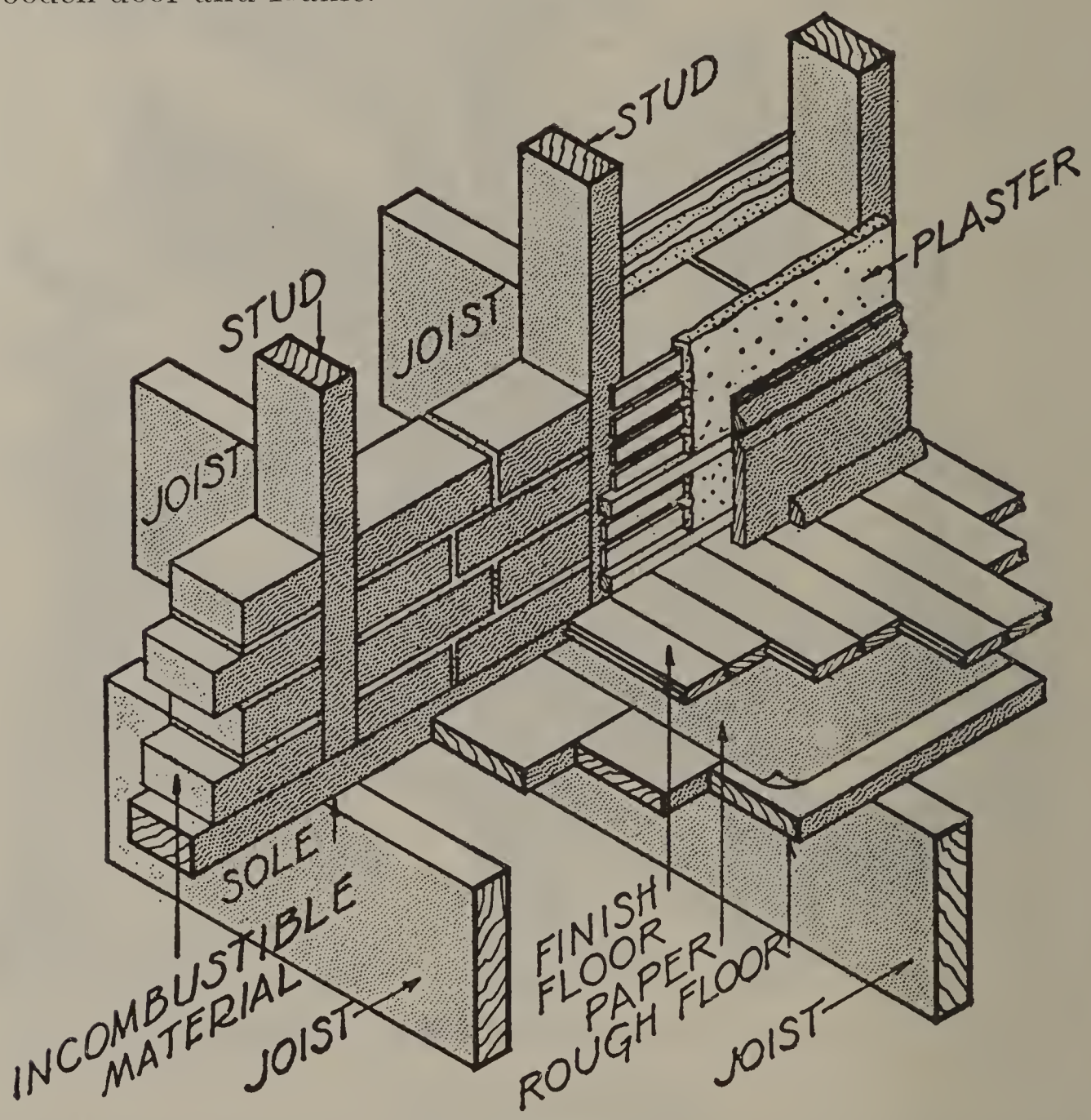


Figure 59.—A method of fire stopping at a partition which is not directly over another partition or support.

Inclosed stairways retard rapid spread of fire from floor to floor. If the interior design calls for an open stairway below, it can often be closed at the top with a flush door.

Shingles

The better grades of shingles are all edge-grain and thick butted; that is, it takes at least five butts to make 2 inches. Edge-grain shingles warp or curl less than flat-grain shingles, thick-butted shingles less than thin shingles, and narrow shingles less than wide ones. Tight, flat shingles offer less opportunity than warped shin-

gles for live cinders to lodge and cause ignition. To follow the accepted rules of good practice in the laying of shingles and in exposure to the weather not only makes a long-lived and economical roof but markedly reduces fire hazard. Painting or staining shingles with materials customarily used for the purpose probably has little effect on their fire resistance.

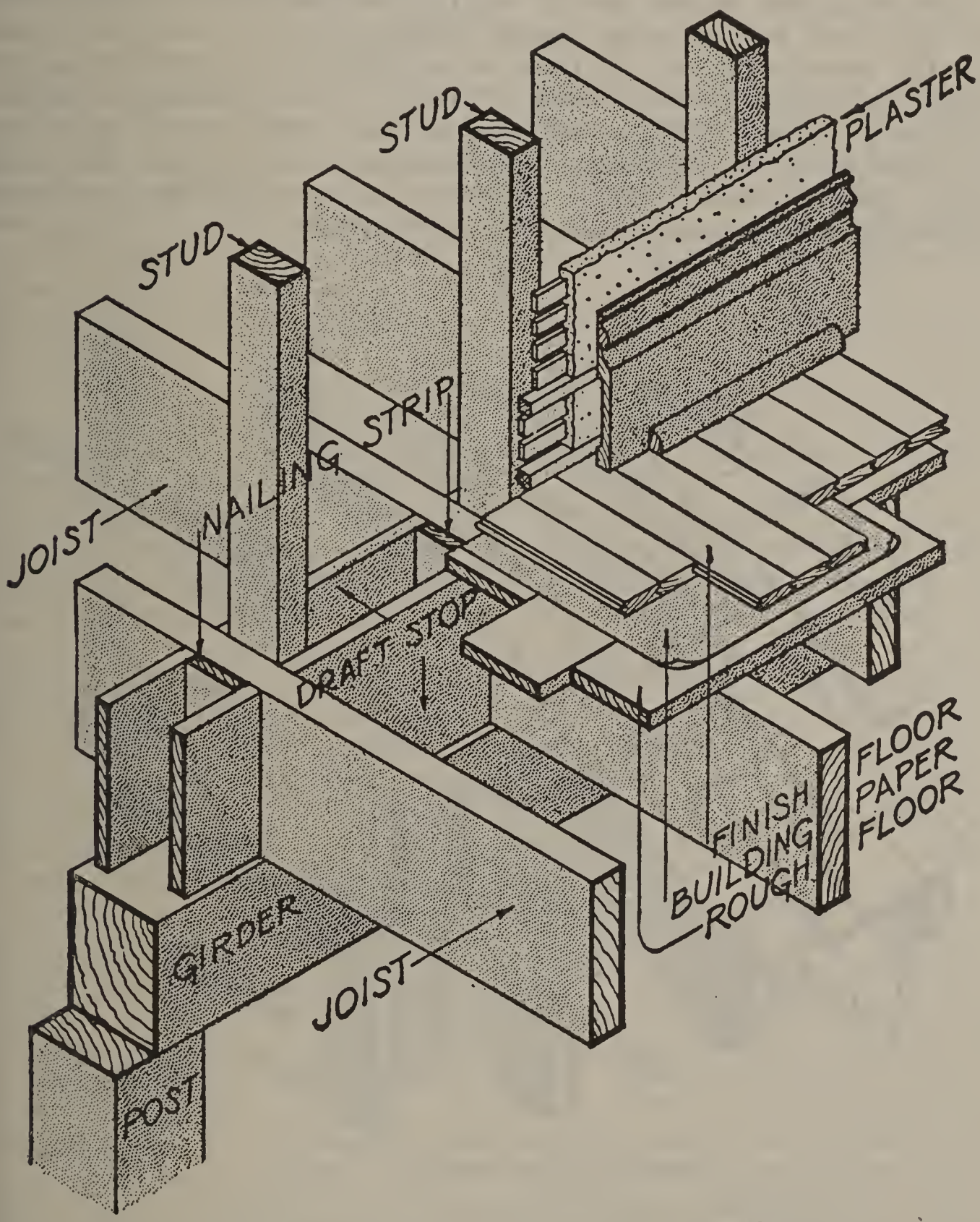


FIGURE 60.—A method of fire stopping at a girder.

FIRE-RETARDANT TREATMENTS FOR WOOD

The two general methods of increasing the fire resistance of wood are (1) by coatings and surface treatments and (2) by impregnation treatments (Cartwright, Garratt, and Truax). Fire-retardant coatings and impregnations are of value chiefly in delaying ignition and checking the spread of fire over wood surfaces. The coatings are sometimes used where more fire-resistant or retardant ma-

terials and methods are unnecessary or impractical, and the impregnations are used mostly for treating wood trim in office or institutional buildings and for scaffolding.

COATINGS AND SURFACE TREATMENTS

Fire-retardant paints are of varying composition and properties but fall into two general classes, namely, special exterior paints usually made with an oil base or a binder, and interior paints, chiefly of the cold-water type (Prince). The cold-water paints, including sodium silicate, whitewash, and some casein products, are among the most effective fire-retardant coatings and are relatively cheap. Most of them, however, are nondurable in outside exposures and are suitable only for interior use.

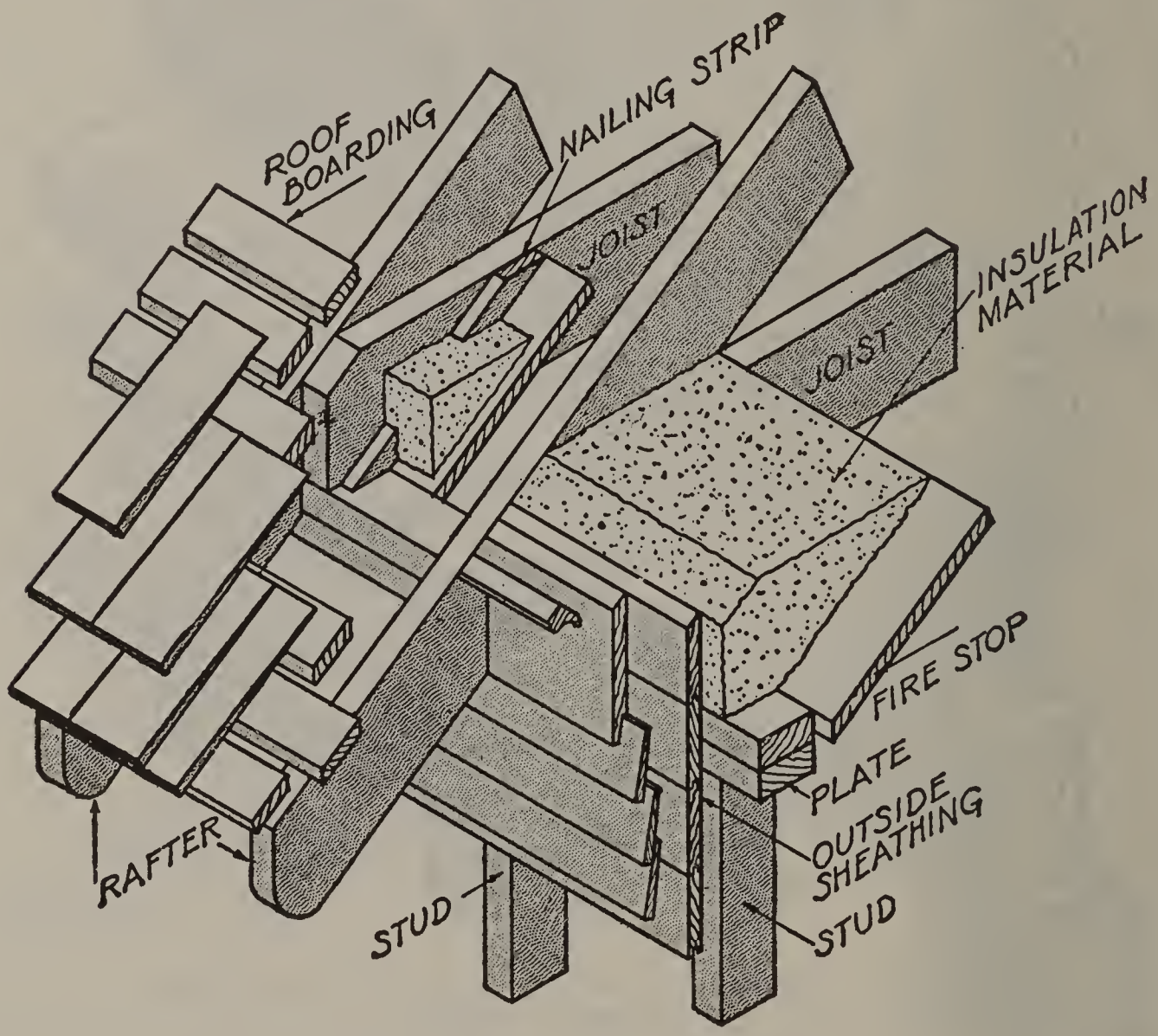


FIGURE 61.—Fire stopping at cornice.

A relatively thick, continuous film or coating of material is necessary to obtain a good fire-retarding effect. A thin coating of even the most effective materials does not add appreciably to the fire resistance of wood structures. Lack of a definite classification of the many kinds and brands of coating materials, as to effectiveness, permanence, and quantity required, preclude the giving of specific recommendations. Effective fire-retardant coatings, properly applied, are of value in delaying ignition and checking the spread of flame originating from small sources. They are not nearly so suitable for protecting against high temperatures for a long time as are impregnation treatments. The best of these coatings are themselves

noninflammable and form a protective film over the wood at high temperatures or emit noncombustible gases that dilute the inflammable gases from the wood or both.

The customary finishing materials for wood, such as ordinary stains, oil paints, varnishes, and lacquers are of no particular value in protecting wood against fire.

IMPREGNATION METHODS

Wood is impregnated with fire-retardant chemicals by methods similar to those in use for the injection of preservatives (p. 270). The wood is sealed within a treating cylinder and the treating solution forced in by means of pressure. While information on the permanence of treatments, their effect on the strength of wood, the amounts required for a specified performance, and other important points is still scant, it may be said that the fire-retarding effect of impregnation treatments is closely related to the quantity of chemical injected into the wood (Associated Factory Mutual Fire Insurance Co., first reference). Absorptions of one-fourth to 1 pound of fire-retardant chemicals per cubic foot of wood, quantities such as are used with toxic chemicals for wood preservation, have only a small effect on the combustion of the wood. It is necessary to use several times as much chemical to obtain the best results. For a thorough impregnation and a high degree of effectiveness approximately 4 pounds of the more effective chemicals per cubic foot of wood are required, or something like 300 pounds per thousand board feet. Effectively fireproofed wood can be charred or disintegrated by continuous exposure to intense heat from an outside source, but when the heating is discontinued the burning ceases. The principal effects of fireproofing treatments are to retard the normal increase in temperatures under fire conditions, to decrease the rate of flame spread and ignition of the wood, to lessen the rate of flame penetration or destruction of wood in contact with fire, and to make fires more easily extinguished.

Impregnation treatments may be complete; that is, the treatment may extend completely through the piece, or they may be only partial in which case only an outside zone of the piece is impregnated. Efficient, complete impregnation with an adequate quantity of fire-retardant chemicals makes wood sufficiently resistant to fire so that it will not of itself support combustion (Hunt, Truax, and Harrison). Partial impregnation affords protection that may be adequate for many purposes and under many conditions, although the central portion is unimpregnated. Only partial impregnation is possible with some species of wood and with large-sized timbers. When the lumber must be cut into smaller-sized pieces or machined after treatment in such a way that the interior is exposed, complete penetration is a necessity. Partial impregnation is obviously cheaper than complete impregnation.

FIRE-RETARDANT CHEMICALS

Many chemicals have a fire-retarding effect when impregnated into wood. Among the most effective chemicals known are diammonium phosphate, monoammonium phosphate, monomagnesium phosphate, and phosphoric acid. They are effective in retarding both flaming

and glowing. The dibasic and monobasic phosphates of ammonia are not only among the most effective single chemicals but also wood treated with them is comparatively free of objectionable properties. Other chemicals that effectively stop combustion when present in larger absorptions are aluminum sulphate, ammonium bromide, ammonium chloride, boric acid, and monobasic zinc phosphate. Still others, such as ammonium borate, lithium chloride, magnesium chloride, sodium arsenate, sodium arsenite, sodium borate (borax), sodium molybdate, and sodium phosphate, are effective in reducing flaming or glowing but not both (Hunt, Truax, and Harrison; and Truax, Harrison, and Baechler).

There are also many combinations of chemicals that are known to be effective as fire retardants, and numerous patents have been issued on so-called "fireproofing" materials, comparatively few of which, however, appear to have actually been used in treating wood commercially. The ammonia salts constitute an important part of most good formulas used in fire-retarding impregnation processes.

Many chemicals that might be used as fire retardants may have undesirable effects on the wood or be objectionable for specific uses. Data are incomplete in this respect; hence due caution should be observed in deciding upon any treatment that has not had thorough trial in practice. Among use characteristics of importance are permanence of fire-resistance, effect on strength of the wood, tendency to corrode metals, effects on paint and glue, hygroscopicity, and toxicity to occupants.

There are a number of impregnation fireproofing treatments of high effectiveness that have been in commercial use over a sufficient period of years to demonstrate that they are practical.

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PAINTING AND FINISHING WOOD

The principal reason for coating woodwork is usually improvement and maintenance of appearance. Immediate considerations in coating wood for appearance are:

(1) Paint or enamel is opaque and therefore conceals the grain and color of the wood, substituting a color, sheen, and texture of its own.

(2) Varnish, lacquer, oil, or wax is transparent, thus revealing the grain of a piece more fully by displacing the air at its surface with a medium of much higher refractive index. In conjunction with stain the color is also altered. The sheen and the texture of the coating are substituted for those of the wood.

(3) Stain without varnish or lacquer changes the color of wood without greatly altering its sheen or texture.

Ultimate considerations in coating wood for appearance are:

(1) Unless protected by moisture-retardant coatings, wood exposed to the weather becomes dull gray in color; smoothly planed surfaces become rough and cracked; boards tend to cup, twist, and pull loose from their fastenings; short boards may split in two; snug joints are loosened; and straight, parallel lines are disarranged. Durable coatings adequately maintained prevent such weathering (Browne, first and fourth references).[34]

(2) Uncoated interior wood surfaces are porous enough to absorb liquids quickly, to stain and spot readily, and to hold dirt tenaciously. Nonporous coatings or coatings that tend to shed liquids protect wood from discoloration and present a surface easily cleaned.

Those parts of buildings that are customarily kept painted are not, as a rule, subject to much hazard of decay by wood-destroying fungi (Browne, first reference) because they are well drained and dry rapidly. Decay and its prevention are discussed on pages 249 to 253 and the painting of wood treated for the prevention of decay on page 232. Ordinary paints and varnishes are not effective as preservatives against fungous decay.

Paint is chosen for exterior woodwork more often than any other coating; it is much more durable than varnish or other transparent coating and usually affords more effective protection against weathering of the wood (fig. 62). Exterior enamel may be used in place of paint where a smoother, harder, and more wear-resistant coating is needed, and the surface may be washed at intervals to keep it clean. It is best to use enamels only on surfaces that are accessible enough to be easily repainted somewhat more frequently than the major surfaces of the building. Porch railings, columns, and window sills, for example, can often be enameled to advantage.

PAINTING CHARACTERISTICS OF WOODS

The same painting procedure and kind of paint are suitable for painting all native softwoods (conifers) and the native hardwoods

[34] For further information, the references at the end of this section should be consulted.

that have relatively small vessels (pores) (Browne, seventh and tenth references). Hardwoods with relatively large vessels require a wood filler before painting or varnishing.

SPREADING RATES ON SOFTWOODS (CONIFERS)

The spreading rate of paint is the area of surface covered by a unit volume of paint. On smoothly planed surfaces of softwoods the spreading rate varies with species only for the first or priming coat of paint applied on the new surface; the spreading rate of subsequent coats does not vary with species (Browne, third reference).

Even for priming-coat paint the species of wood has less effect on spreading rate than the individuality of the painter or the kind and proportion of ingredients in the paint. Some painters brush paint out farther than others; the best painters apply paint in

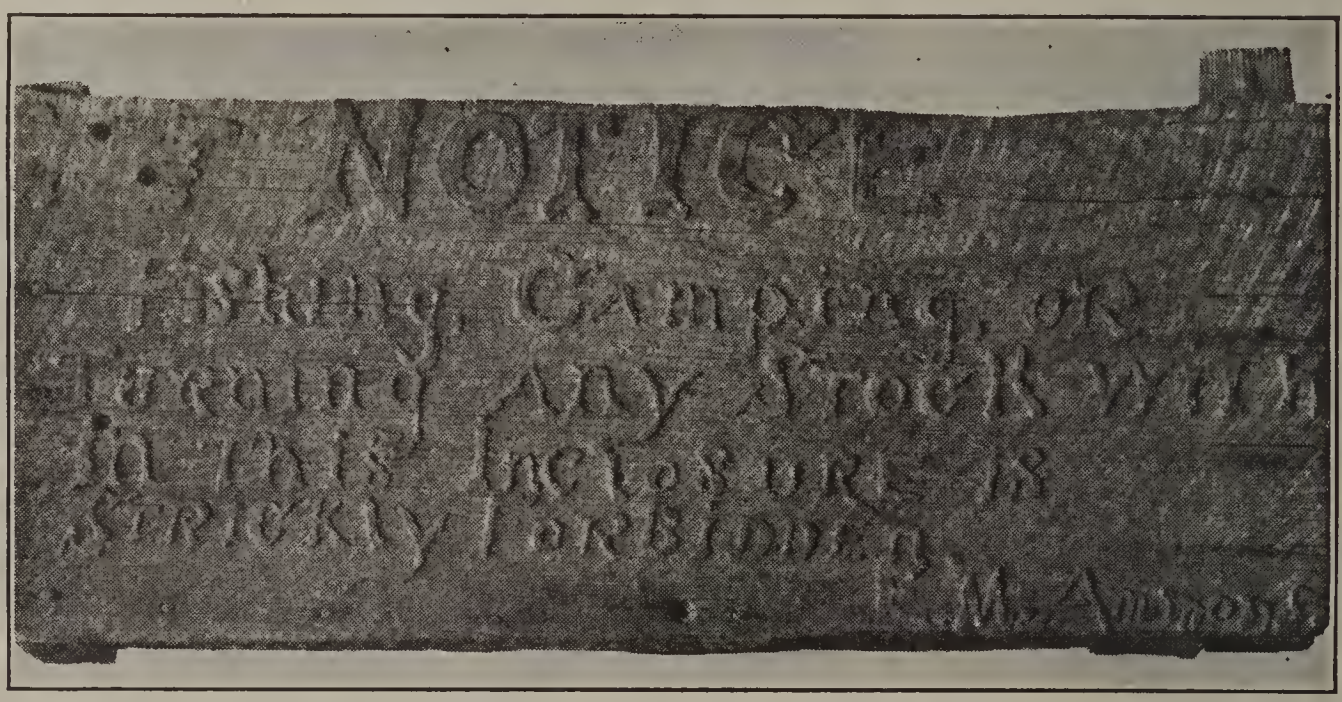


FIGURE 62.—A good example of protection against weathering afforded by paint. After many years of service only the painted letters on this sign resisted erosion.

fairly thick coats roughly 600 square feet per gallon, while unskilled painters very often apply coating too thin, covering as much as 1,000 or 1,200 square feet per gallon. A few of our native softwoods tend to take 10 or 12 percent more priming-coat paint than the average, and a few tend to take as much less. By the time second-coat and third-coat paints have been applied, however, the difference in paint consumed amounts to only 3 or 4 percent above or below the average, a value that is probably within the limits of uniformity with which a good workman will paint at different times. The woods that tend to take more than the average amount of paint are, in general, the lightweight ones and those that tend to take less paint are the heavy ones that have a high proportion of summer wood. Rough surfaces, such as shingles, the sawed side of bevel siding, weathered wood, or surfaces on which repainting has been neglected for a long time may consume twice the amount of priming-coat paint required for smoothly planed surfaces.

DRYING OF PAINT ON SOFTWOODS

The time required for a coating of paint to dry—that is, to harden—usually depends almost entirely on the composition of the

paint, the intensity of sunlight, and the temperature and relative humidity of the atmosphere. The drying is retarded, however, if the wood is wet when painted; its moisture content should not exceed 20 percent. On wet redwood or southern cypress, priming-coat paint may remain liquid for days, especially when the paint is one containing little or no white lead or zinc sulphide pigment (~~Schmutz and Palmer~~). On air-dry redwood paint hardens as rapidly as on any other wood. On air-dry cypress in the absence of sufficient sunlight paint may take longer than usual to harden. Cypress boards that contain much more than the average amount of the oily extractive material characteristic of cypress may retard the hardening of paints lacking white lead or zinc sulphide even when the boards are reasonably dry unless the drying takes place in strong sunlight.

(c) FILLING POROUS HARDWOODS BEFORE PAINTING

For painting purposes the hardwoods may be classified as follows:

Hardwoods with large pores:
- Ash
- Butternut
- Chestnut
- Elm
- Hackberry
- Hickory
- Khaya (African mahogany)
- Mahogany
- Oak
- Sugarberry
- Walnut

Hardwoods with small pores:
- Alder, red
- Aspen
- Basswood
- Beech
- Cherry
- Cottonwood
- Gum
- Magnolia
- Maple
- Poplar
- Sycamore

Birch has pores large enough to take wood filler effectively when desired but small enough, as a rule, to be painted satisfactorily without filling.

Hardwoods having small pores may be painted with ordinary house paints in exactly the same manner as softwoods. For hardwoods with large pores, however, the usual priming-coat paint should be replaced with a wood filler, which is a paste consisting of pigment, chiefly ground quartz, mixed with linseed oil and a paint drier.

Filler is necessary on woods having large pores because paint applied by brush or spray gun does not fill the pores properly. Without filler the pores not only appear as depressions after the painting has been finished but also act as centers from which disintegration of the coating sets in.

(d) EFFECT OF NATURE OF WOOD ON WEARING OF PAINT

During the first year or two after an exterior wood surface has been painted or repainted properly the nature of the wood usually has very little effect on the behavior of the paint coating. Later on, when the coating has become embrittled with age, differences between woods become very important and very largely determine how rapidly the coating disintegrates. Under normal conditions of exposure—that is, when the moisture conditions discussed on page 240 do not pertain—paint coatings on wood (~~Browne~~, eighth, eleventh, and thirteenth references) deteriorate most rapidly where the greatest

amount of sunshine falls and deterioration proceeds in successive but overlapping stages as follows:

(1) The soiling stage. The coating gradually becomes dirty.

(2) The flatting stage. The coating loses its gloss.

(3) The chalking stage. Dirt may be thrown off more or less completely, but colors appear to fade.

(4) The fissure stage. Fissures are of two general types, depending upon the nature of the paint (~~pl. 4~~):

(*a*) Checking. The fissures are at first superficial but later may penetrate entirely through the coating.

(*b*) Cracking. The fissures pass entirely through the coating when first observed. The coating at the edges of the cracks sooner or later comes loose from the wood and curls outward. As a rule cracking comes at a more advanced stage of paint embrittlement than checking.

(5) The stage of disintegration. Behavior in the fissure stage determines the form in which disintegration takes place:

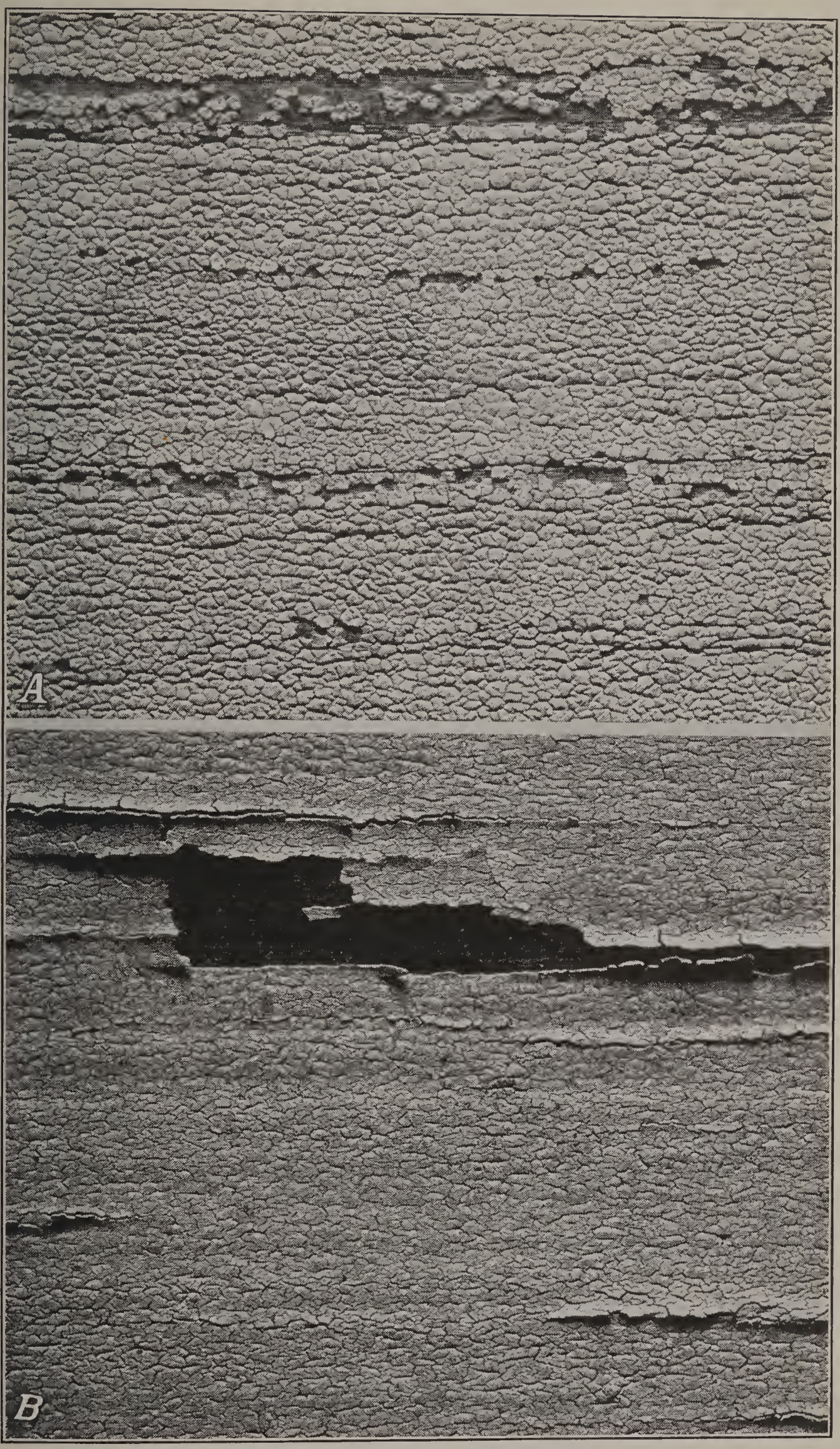
(*a*) Crumbling, which develops from checking, consists in the falling away of tiny fragments of coating cut off when the fissures become interwoven and penetrate entirely through the coating.

(*b*) Flaking, which develops from cracking and curling. The loosened edges of coating that curl outward finally fall off, after which the newly formed edges curl outward and the process continues. Flaking is usually a more rapid form of disintegration than crumbling.

From the time that cracking or disintegration begins the nature of the wood painted dominates the further rate of progress of failure. On softwoods cracking, crumbling, and flaking progress chiefly over the bands of summer wood. The wider the bands of summer wood intersected by the painted surface the more rapidly disintegration proceeds and the more conspicuous the areas laid bare. Repainted coatings behave in much the same way as coatings applied to new wood except that the fragments of coating that fall off may be somewhat larger and may not begin to come off quite so soon.

The following wood properties or characteristics (~~Browne, sixth~~ reference) largely determine how long softwood boards retain paint satisfactorily: (1) Wood of light weight (low density) holds paint longer than heavy wood because light wood contains less summer wood; (2) narrow-ringed wood holds coatings longer than wide-ringed wood because the bands of summer wood are narrower; (3) edge-grain surfaces hold coatings longer than flat-grain surfaces, also because the bands of summer wood are narrower at the surface; (4) flat-grain boards may hold paint better on the bark side than on the pith side because on the pith side there is sometimes a tendency for the edges of the bands of summer wood to loosen and curl outward, thus dislodging the coating; and (5) high-grade lumber holds coatings better than low-grade both because knots and other defects hold paint poorly and because the low grades usually come from the center of the tree where the wood is likely to be wider ringed.

Coatings begin to fail to protect wood against weathering when deep fissures develop. The consequences of inadequate protection depend upon the characteristics of the wood. Edge-grain boards are less seriously affected than flat-grain boards of the same species.



A, Disintegration of a paint coating by crumbling. The interweaving fissures, known as recitulate checking, were at first superficial but in the course of time they penetrated entirely through the coating. Now tiny fragments of coating cut off by the fissures are beginning to fall away from the bands of summer wood in the wood beneath. The area shown here is magnified × 4.4.

B, Disintegration of a paint coating by flaking. Checking was retarded in this paint by suitable choice of pigments and the checking is still superficial but cracking has started in the embrittled coating, the coating comes loose over the bands of summer wood in the wood beneath and curls upward at the edges of the cracks. Finally the curled edges of coating break off. The area shown here is only 1 by 1 inch in size. The coatings shown in *A* and *B* are similar in age and in all respects except the pigment composition of the paint.

Woods that hold their shape well and do not develop conspicuous checks or cracks on weathering are less seriously affected by inadequacy of paint protection than are other woods.

CLASSIFICATION OF SOFTWOODS FOR PAINTING

Table 45 classifies native softwoods by species with respect to their painting characteristics for exterior use (Browne, sixth and ninth references). The classification is based upon the average behavior of commercial shipments of select grades of the different woods; that is, upon material of a quality that may be used for house siding or millwork. Boards of any one species may vary widely in paint retention so that, in general, boards selected for the physical properties that favor paint durability will serve much more satisfactorily than the average run of the species rated in table 45.

TABLE 45.—*Classification of softwoods for painting*

Group 1 [1]	Group 2 [2]	Group 3 [3]	Group 4 [4]
Alaska cedar. Incense cedar. Northern white cedar. Port Orford cedar. Southern white cedar. Western red cedar. Southern cypress. Redwood.	Northern white pine. Western white pine. Sugar pine.	Commercial white fir. Eastern hemlock. Western hemlock. Ponderosa pine. Lodgepole pine. Eastern spruce. Engelmann spruce. Sitka spruce.	Douglas fir. Western larch. Norway pine. Southern yellow pine. Tamarack.

[1] Woods that hold paint longest and suffer least when protection against weathering becomes inadequate.
[2] Woods that hold white-lead paint as long as those of group 1 but do not hold mixed-pigment paints quite so long and suffer more than those of group 1 if protection becomes inadequate.
[3] Woods that do not hold either white-lead paint of mixed-pigment paints so long as woods of group 1 and suffer more than woods of group 1 if protection becomes inadequate.
[4] Woods that do not hold paint coatings so long as woods of group 3.

EFFECT OF EXTRACTIVES IN WOOD ON PAINT BEHAVIOR

In general, the extractives in wood have much less effect on paint behavior than has been commonly supposed. They are far less important than the width of the bands of summer wood.

Distinction must be made between piny resins, which are characteristic of pines but occur also in other softwoods, and other extractives.

Piny resins consist of a solid rosin and a volatile liquid such as turpentine. They affect paint unfavorably by exuding through coatings, leaving unsightly encrustations. Exudation is minimized by thorough seasoning of the lumber to drive out the turpentine, rendering the resin less mobile. Much longer seasoning is necessary to remove turpentine than to remove moisture (Browne and Hrubesky). The piny resins may also be responsible for the fact that paints containing zinc oxide fail somewhat more rapidly on the pines than they do on other softwoods having bands of summer wood of similar width.

Other extractives in wood may have a favorable effect on the durability of paint (Browne, sixth reference). There is evidence that such is the fact with extractives in redwood and southern cypress, although colored extractives in redwood and red cedar that

are soluble in water may exude through coatings if the wood beneath the coatings becomes very wet; under normally dry conditions these discolorations do not occur.

EFFECT OF IMPREGNATED PRESERVATIVES ON PAINTING

Wood treated with the water-soluble and other somewhat colorless preservatives in common use can be painted satisfactorily. The life of the coating may in some instances be slightly less than it would have been on untreated wood, but the loss in durability is not enough to offer any practical objection to the use of treated wood for purposes where preservation against decay is necessary and the appearance of painted wood and protection against weathering are desired (Browne, seventeenth reference). Coal-tar creosote or other dark oily preservatives tend to stain through paint and no entirely satisfactory method of painting over them is known (Dunlap), but fairly good results can be obtained with 1 or 2 coats of exterior aluminum paint.

CHOICE OF PAINTS FOR EXTERIOR WOODWORK

House paints of the best quality are recommended for nearly all needs for exterior painting. Inferior paints made to sell at materially lower prices must be applied in greater amount to accomplish the same result, may not last so long, and are less reliable generally. Even when low initial cost of painting is the chief consideration it usually proves cheaper to use high-grade paint in the minimum number of coats because the labor for a paint job usually costs several times as much as the paint. For both low initial cost and great durability, whenever the colors are acceptable, paints of good quality made with iron oxide pigments are more economical than most other good paints. Two coats of exterior aluminum paint make an exceedingly durable, highly protective coating when a metallic appearance is not considered undesirable. For very brief service or where very frequent repainting is desired for some reason and protection against weathering is not necessary, old-fashioned white-wash or modern types of exterior water or water-emulsion paints are safer to use than linseed oil paints of very inferior quality. The water paints give their best service on rough rather than on smoothly planed wood.

For residences or buildings of architectural pretension white or light-colored paints are most popular for the major painted surfaces, supplemented if desired by deeply colored paints on minor surfaces. When deep colors are appropriately dominant it is often better and more economical to use rough wood surfaces such as shingles or the sawed side of siding and apply exterior stains rather than gloss paints.

PASTE AND PREPARED PAINTS

Paste paints contain a greater proportion of pigment than prepared paints and must be thinned with more linseed oil and turpentine to make them ready for application. As a rule paste paints manipulated by a skillful painter in accordance with the particular conditions prevailing on the job permit closer adherence to the traditional technique of the paint craft than is possible with prepared paints. For example, in table 46 the second-coat mixture for three-

coat painting and in table 47 the first-coat mixture for repainting contain less linseed oil in proportion to pigment than the manufacturer of prepared paint has already incorporated. For that reason these mixtures practically can be made only from paste paints. In congested parts of the South where mildew is troublesome, it is advantageous to mix even the finish-coat paint with less linseed oil than is already present in prepared paint.

On the other hand, unskilled or unscrupulous painters can make far more serious blunders in manipulating paste paint than they can make with prepared paint. The manufacturer of prepared paint can also make sure that a larger proportion of the linseed oil used in the paint is of the type most compatible with the particular kinds of pigments he has used. Further advantages of prepared paints lie in the fact that they are commonly sold in a much greater variety of colors than paste paints, so that tinting by the painter is often unnecessary and they are simpler for the ordinary home owner to use for general household painting purposes.

COMPOSITION OF PAINT

The quality of a house paint depends upon the quality of the liquids, the quality of the pigments, and the proportions of pigments and liquids of which it is made (Browne, eleventh reference).

Quality of the Liquids

Linseed oil is the most widely accepted liquid ingredient for exterior paints for wood. It is available in many degrees of refinement for different purposes. Proper choice of the kind of linseed oil most suitable for the pigments used is essential for making high-grade paint, but as a rule the purchaser must rely upon the manufacturer's judgment in selecting the kind of oil. Substitution of other drying oils for part of the linseed oil is not necessarily detrimental to the quality of the paint. In most high-grade paste or prepared paints from 80 to 100 percent by weight of the liquid consists of linseed oil or linseed oil and other drying oils. For the painter's needs in thinning paints for application, raw or boiled linseed oil of good quality should be used. The oil for thinning mixed-pigment paints should have an acid number not exceeding 4.

Varnish is rarely a desirable ingredient in the liquid of good house paint (except in aluminum paint, p. 239), but cheap varnish is often used in inferior paints because large proportions of volatile thinners, which are inexpensive, can then be incorporated. On the other hand, good exterior varnish or heat-treated linseed oil or tung oil is necessary to make exterior enamels or exterior floor paints, which must stand mechanical wear as well as weather. In such enamels or floor paints of good quality as much as 50 percent by weight of the liquid may be volatile thinner. Synthetic drying oils are now manufactured for paint oils; they make paints that dry faster than linseed-oil paints, but they have not been in use long enough for their merits to be well established.

The volatile thinner in most paints is mineral spirits, a petroleum product, but turpentine is commonly recommended for painters to use in thinning paint. There should be no more than 1 or 2 percent by weight of water in the liquid of any good paint.

Quality of the Pigments

Differences in the behavior of linseed-oil paints during the successive stages in deterioration with age (~~p. 229~~) are determined largely by the nature of the pigments. No kind of paint now known is superior in all stages of deterioration; improvement in one stage is usually effected at some sacrifice in other stages. For that reason the user's judgment about the relative importance of the different stages, and particularly about the stage at which he expects to repaint, determines what kind of paint he can use to best advantage. For intelligent paint maintenance, therefore, the user should know the pigment composition of the paint and its bearing upon behavior during deterioration.

The opaque white pigments predominate in the pigment of good white paints. Tinted paints, which include the majority of colored house paints, are essentially white paints containing minor proportions of colored pigments. The good white paints and white base paints for tinting may be grouped for convenience into pure white-lead paint, lead and zinc mixed-pigment paints, and mixed-pigment paints containing modern, very opaque pigments.

In pure white-lead paint the pigment is entirely basic carbonate white lead. During the soiling and flatting stages of its life white-lead paint may become dirtier than mixed-pigment paints, especially in congested urban locations or when applied in the late fall, winter, or early spring, or in deeply shaded places. Chalking of white-lead paint and apparent fading, if it is tinted, usually set in fairly early, after which the dirt is thrown off promptly and evenly, leaving a clean surface which may, however, contrast strongly with deeply shaded parts of the building that are still dirty and not yet faded. Checking begins comparatively early, usually inconspicuously, and gradually works deeply into the coating, but probably for that reason cracking and flaking rarely occur (~~pl. 4~~). The outstanding merit of white-lead paint is the long interval between checking and beginning of crumbling and the slow progress of crumbling in the stage of disintegration, especially on woods of groups 1 and 2 in table 45. Even badly neglected white-lead-painted surfaces can usually be covered fairly smoothly and durably with new paint unless large weather checks have developed in the wood. Initial painting with white-lead paint provides a very satisfactory foundation for subsequent painting with mixed-pigment paints, but it is not advisable to apply pure white-lead paint over mixed-pigment paints because checking may then assume the conspicuous form known as "alligatoring."

In good mixed-pigment paints of the lead-and-zinc type, part of the basic carbonate white lead is replaced by zinc oxide, and another and smaller part may or may not be replaced by inexpensive transparent pigments such as magnesium silicate, silica, barium sulphate, clay, or calcium carbonate. In such paints basic carbonate and basic sulphate white lead are commonly considered interchangeable, either one or any mixture of the two may be used for the white-lead content of the pigment. Incorporation of the zinc oxide reduces the chances of excessive soiling of the coating and retards both chalking and checking. Appearance during the soiling, flatting, and chalking stages may therefore be somewhat better than that of pure white-

lead paint, especially if the paint is tinted, but on the other hand the coating may remain dirty longer. Ultimate disintegration of lead and zinc paints usually takes place by cracking, curling, and flaking (pl. 4). Long neglect of repainting after flaking starts, especially if the content of zinc oxide is high, may leave a surface that cannot be smoothly and durably repainted without removing the old coating completely. Federal Government Specification TT–P–36 for lead-and-zinc paint requires that the content of white lead shall be not less than 60 percent by weight and the sum of the white lead and zinc oxide not less than 90 percent of the total pigment. Transparent and colored pigments together must therefore be limited to 10 percent of the total pigment. Some authorities who regard this as a satisfactory specification for white paint think that in tinted paints the minimum content of white lead should be 50 percent and the minimum sum of white lead and zinc oxide 85 percent of the total pigment. In parts of the South where the relative humidity is always high, chalking and fading of paint are stimulated while cracking and flaking are retarded and paints are subject to the growth of mildew. For such a climate it is advantageous to increase the content of zinc oxide to as much as 50 percent of the total pigment.

Mixed-pigment paints containing very opaque white pigments may be considered conveniently as lead-and-zinc paints in which part or all of the white lead is replaced by one of the titanium pigments, by one of the zinc sulphide pigments, or their mixtures. Good paints of this type are characterized by unusual freedom from dirt in the soiling stage and prompt shedding of dirt in the chalking stage. When white lead is replaced entirely by one of the titanium pigments development of fissures may be greatly retarded and checking entirely prevented; but if repainting is postponed long enough, cracking and flaking ultimately set in as they do in the mixed-pigment paints already discussed. The most popular titanium pigment for exterior paints is a mixture of 25 percent titanium dioxide and 75 percent barium sulphate by weight. Some paint manufacturers prefer to use pure titanium dioxide, in which case it is good practice to consider a mixture of 1 part by weight of titanium dioxide together with about 1¾ parts of magnesium silicate, silica, or calcium carbonate as the titanium pigment that can properly replace 2¾ parts of white lead in good lead-and-zinc paint. The most important zinc sulphide pigment is lithopone which contains about 30 percent zinc sulphide and 70 percent barium sulphate. Pure zinc sulphide is now used in a few brands of house paint.

Dull red, brown, and yellow pigment paints are made most economically with iron oxide pigments, either natural earths or manufactured pigments. For good retention of color and maximum durability the content of iron oxide in the pigment may well be 80 percent by weight or more and should certainly be not less than 30 percent. Bright reds require organic lake pigments that are more expensive and less durable than iron oxide reds. Bright yellows and oranges are made with chrome yellows (lead chromate and basic lead chromate) which are fully as expensive as white pigments but are more durable. Greens are made with chrome green, which is a mixture of chrome yellow and prussian or chinese blue (iron ferro-

cyanide). Durable blacks are made with carbon pigments, such as lampblack; asphalt paints make cheaper but less durable blacks for exposure to the weather. When color permits, colored-pigment paints often retain color and protective power better if they contain some zinc oxide or white lead. If they do not, it is advisable to apply them over priming coats of white-lead or aluminum paint.

Proportions of Pigments and Liquids

Durability as well as color and capacity are imparted to paint by pigments. For that reason there is an optimum proportion of pigments and linseed oil in good paint. Although the optimum proportions have not been determined accurately to the satisfaction of all authorities, it is known to be good practice with the paints described herein to keep the pigment volume, which is the percentage by volume of total pigment to total nonvolatile ingredients, within the range of 25 to 32 percent in the finish-coat paint. At the lower end of this range or below it, paints may become unnecessarily dirty; while at the upper end of the range or above it, they may lose gloss rapidly and begin to chalk and fade early. Prepared paints, and paste paints when thinned for application as finish coats, should contain enough total pigment to fall within this range, preferably nearer the upper part of it. Inferior paints, unless they contain very large proportions of transparent pigments, are usually deficient in content of total pigment. The painter can readily add more linseed oil if it should be desirable, but it is seldom practicable to remove excess oil from prepared paint.

Once the correct ratio of pigment and linseed oil has been established, some volatile thinner is usually necessary to obtain good brushing consistency and convenient application at the proper spreading rate. Paints that require unusually large amounts of thinner to establish good consistency have "false body" and may justly be regarded as of questionable quality.

The pigment volume in paint is not customarily indicated in the manufacturer's statement of composition, which gives the proportions of ingredients by weight, but it can be easily calculated if the specific gravity of each of the ingredients is known. Tables of the specific gravities of the important ingredients of paint are available (Gardner).

EXTERIOR STAINS

Exterior wood stains are essentially paints greatly diluted with linseed oil, a volatile thinner, and sometimes creosote. Stains are cheaper than paints, but they do not protect wood against weathering and are therefore most suitable for rough surfaces, such as shingles or siding placed with the sawed side out. Good stains should contain only pure, finely divided, opaque pigments, free from transparent pigments. The pure iron oxide, chrome, and carbon pigments are very satisfactory; white pigments less so. The liquid part of the stain should be at least one-third linseed oil by volume, with two-thirds recommended by some authorities. Particular merits are claimed for stains made with pigments ground in very highly bodied linseed oil because the pigments are more highly dispersed in such

liquids and become more deeply embedded in rough wood surfaces. Houses with shingles or siding with the sawed side out, stained with colored-pigment stains, and with smoothly planed and painted wood trim often have the trim painted twice for every time that the side walls are stained.

VARNISHES

Transparent finishes are rarely practicable on exterior surfaces fully exposed to the weather, except on small, easily accessible surfaces such as doors, because even the best varnishes are far less durable than paints. When transparent finishes are used, prompt renewal of the varnish when needed is essential to prevent the wood from turning permanently gray.

APPLICATION OF PAINT

Wood should not be painted when it is wet. As long as there is no free water present, however, the moisture content is of minor importance; wood painted at 16- to 20-percent moisture content holds paint slightly longer than wood painted at 10-percent moisture content. Paint dries very slowly at low temperatures; painting should therefore not be done at times when the temperature is likely to fall below 40° F. When there is danger of dew or frost at night application of paint should cease several hours before sunset. In clear, warm weather coatings of paint can be applied within 24 hours of each other if necessary, but it is better practice to allow at least 2 or 3 days. On the other hand, it generally is inadvisable to allow more than 1 or 2 weeks to elapse between successive coats.

On new houses faulty methods of drying the interior plastering that drive moisture into the sheathing and siding (Browne, fifth reference, and Hartwig) cause blistering and peeling of paint (p. 240). If there is doubt about the moisture content within the side wall, it is best to apply only the priming coat to the exterior woodwork and defer the remaining coats until the walls are thoroughly dry. The priming coat will not blister; but on the other hand it furnishes only partial protection against weathering, so that the painting should be completed as soon as it its safe to do so.

On new wood surfaces or on painted surfaces on which the old coating has not yet become deeply cracked, paint may be applied by brush or spray gun with equally serviceable results. Over old coatings that have passed well into the fissure or the flaking stage of paint deterioration, however, sprayed paint may not prove so durable as brushed paint.

The conventional procedure in painting new wood surfaces calls for the application of three coats of paint, a priming coat, second coat, and finish coat. Usually the three coats are made of the same kind of paint except for differences in proportions of pigments, linseed oil, and turpentine, but the current trend is toward the use of special paints for priming coats. Much painting of new wood is now done with only two coats, but this practice frequently leads to unsatisfactory results. When properly done 2-coat painting is practicable, but it requires much more skillful workmanship than 3-coat painting.

MIXING OF PAINT

In three-coat painting of new wood surfaces it is well-established practice for the priming-coat paint to have a pigment volume between 20 and 25 percent, the second-coat paint 35 to 40 percent, and the finish-coat paint 25 to 32 percent. The high pigment volume in the second coat requires the use of paste paint. With prepared paint it is generally necessary to have the same pigment volume in the second and finish coats, but the second coat should never have a lower pigment volume than the finish coat. In two-coat painting of new wood both coats may have 25 to 32 percent of pigment volume, and they should be applied thicker than is customary in three-coat painting. Table 46 presents suitable directions for thinning paste paints in accordance with the foregoing practices, provided the approximate proporation of total pigment in the paste paint is known. When using prepared paint the painter has little control over the pigment volume. In general, not more than 1 quart of linseed oil and 1 pint of turpentine should be added to a gallon of prepared paint for the priming coat, and the second coat should be thinned with 1 pint of turpentine and no linseed oil. As a rule, no addition is made to prepared paint for finish coat.

TABLE 46.—*Approximate amounts of linseed oil and turpentine to be added to 1 gallon of paste paint for painting new wood surfaces*

Reduction and spreading rate	For 3-coat initial painting			For 2-coat initial painting	
	First coat	Second coat	Third coat	First coat	Second coat
For soft paste [1] white-lead paint and other paste paints containing more than 50 percent pigment by volume:					
Raw linseed oil [2]—quarts	6	2	4	4	4
Turpentine—do	1½	1⅔	0	1	0
Spreading rate [3]—square feet per gallon	575	600	600	450	500
For paste [1] paints containing 40 to 50 percent pigment by volume:					
Raw linseed oil [2]—quarts	5	1½	3	3	3
Turpentine—do	1	1	0	1	0
Spreading rate [3]—square feet per gallon	575	600	600	450	500
For paste [1] paints containing less than 40 percent pigment by volume:					
Raw linseed oil [2]—quarts	3½	1	2	--------	--------
Turpentine—do	1	1	½	--------	--------
Spreading rate [3]—square feet per gallon	550	575	575	--------	--------

[1] If the paste paint contains no drier about ⅓ pint of liquid paint drier should be added in each of the above mixtures.

[2] Boiled linseed oil should be used in place of raw linseed oil only if the manufacturer indicates that it is satisfactory to do so.

[3] If additional thinning is necessary to give good brushing consistency, thin further with turpentine, not with linseed oil, and apply the paint at correspondingly lower spreading rate. For congested urban districts where paint becomes very dirty or where mildew is troublesome, the amount of linseed oil added to finish coats may be reduced by about 1 pint and the amount of turpentine increased by about ¾ pint.

Changes in priming-coat reductions according to the nature of the wood painted are often recommended in the mistaken belief that the differences in painting characteristics of woods can be offset in that way. The priming-coat mixtures given in table 46 are suitable for all native softwoods. For resinous woods such as southern yellow pine the common suggestion to mix priming coats with

more than the usual proportion of turpentine is very definitely bad practice.

The durability of paint on woods of groups 3 and 4 of table 45 can often be materially increased by using special priming paints. Pure white-lead paint when used as a priming paint over which mixed-pigment paints are applied, especially paints high in zinc oxide, may be considered a special priming paint for this purpose. The experience of the Forest Products Laboratory so far indicates that the most effective special priming paint on woods of groups 3 and 4 is exterior aluminum paint (Browne, seventh, fourteenth, fifteenth and sixteenth references, and Edwards and Wray). Aluminum priming paint is made usually with 2 pounds of dry aluminum powder, standard varnish grade, or 2 pounds of commercial paste aluminum in 1 gallon of long-oil spar varnish made specifically for that purpose. The right kind of varnish must be used. Neither ordinary spar varnish, which is both unsuitable and too expensive, nor cheap bronzing liquid for interior use is acceptable for exterior aluminum paint. When properly applied the aluminum primer hides the surface of the wood completely. Aluminum priming paint, in common with other colored primers, makes checking in those paints in which it occurs somewhat more prominent; but if the aluminum primer is a suitable one, it does not hasten the development of checking or alter the pattern in which it occurs.

5. REPAINTING

The fundamental factor in good paint maintenance is to repaint at the right time. Neglect of repainting results in damage that cannot be satisfactorily repaired by mere application of paint. Warped and checked boards are not restored by paint, and a badly broken old coating cannot be covered smoothly without first removing it entirely, which is an expensive operation (Browne, twelfth reference).

It sometimes happens that a relatively small number of boards on a house lose their paint much sooner and more conspicuously than the rest of the boards. In such cases the average life of subsequent coatings can often be increased by replacing these boards with new ones chosen for good painting characteristics in accordance with the principles stated on page 230.

Those who are willing to repaint often to maintain the best possible appearance may do their repainting at some time during the chalking stage of deterioration. They should either have two coats applied fairly thinly or else have the dirt washed off thoroughly and only one substantial coat of paint applied.

Those who wish to repaint as infrequently as is consistent with good maintenance usually wait for the stage of fissures or the very early part of the stage of disintegration before repainting. Two coats are then advisable and are usually necessary if crumbling or flaking has begun. Any loosened parts of the old coating should be removed with a putty knife, wire brush, or sandpaper. Conspicuous spots of bare wood should be touched up with priming-coat paint. Two full coats of paint should then be applied. Table 47 may be used as a guide for thinning paste paints for repainting according to the same principles on which table 46 for initial painting is based.

TABLE 47.—*Approximate amounts of linseed oil and turpentine to be added to 1 gallon of paste paint for repainting during the fissure stage or the very early stage of disintegration of the old coating*

Reduction and spreading rate	First coat	Second coat
For soft paste [1] white-lead paint and paste paints containing more than 50 percent pigment by volume:		
Raw linseed oil [2] ---- quarts	2⅔	4
Turpentine ---- do	2⅓	0
Spreading rate [3] ---- square feet per gallon	600	600
For paste [1] paints containing 40 to 50 percent pigment by volume:		
Raw linseed oil [2] ---- quarts	1⅔	3
Turpentine ---- do	2	0
Spreading rate [3] ---- square feet per gallon	600	600
For paste [1] paints containing less than 40 percent pigment by volume:		
Raw linseed oil [2] ---- quarts	1	2
Turpentine ---- do	2	½
Spreading rate [3] ---- square feet per gallon	575	575

[1] If the paste paint contains no drier about ⅓ pint of liquid paint drier should be added in each of the above mixtures.

[2] Boiled linseed oil should be used in place of raw linseed oil only if the manufacturer indicates that it is satisfactory to do so.

[3] If additional thinning is necessary to give good brushing consistency, thin further with turpentine, not with linseed oil, and apply the paint at correspondingly lower spreading rate. For congested urban districts where paint becomes very dirty or where mildew is troublesome, the amount of linseed oil added to finish coats may be reduced by about 1 pint and the amount of turpentine increased by about ¾ pint.

If repainting is neglected until long after flaking sets in, the surface may present a difficult and uncertain problem in repainting unless the old paint was one that stands neglect well. The safest procedure may be to burn off the old coating completely and repaint with three coats as for new wood.

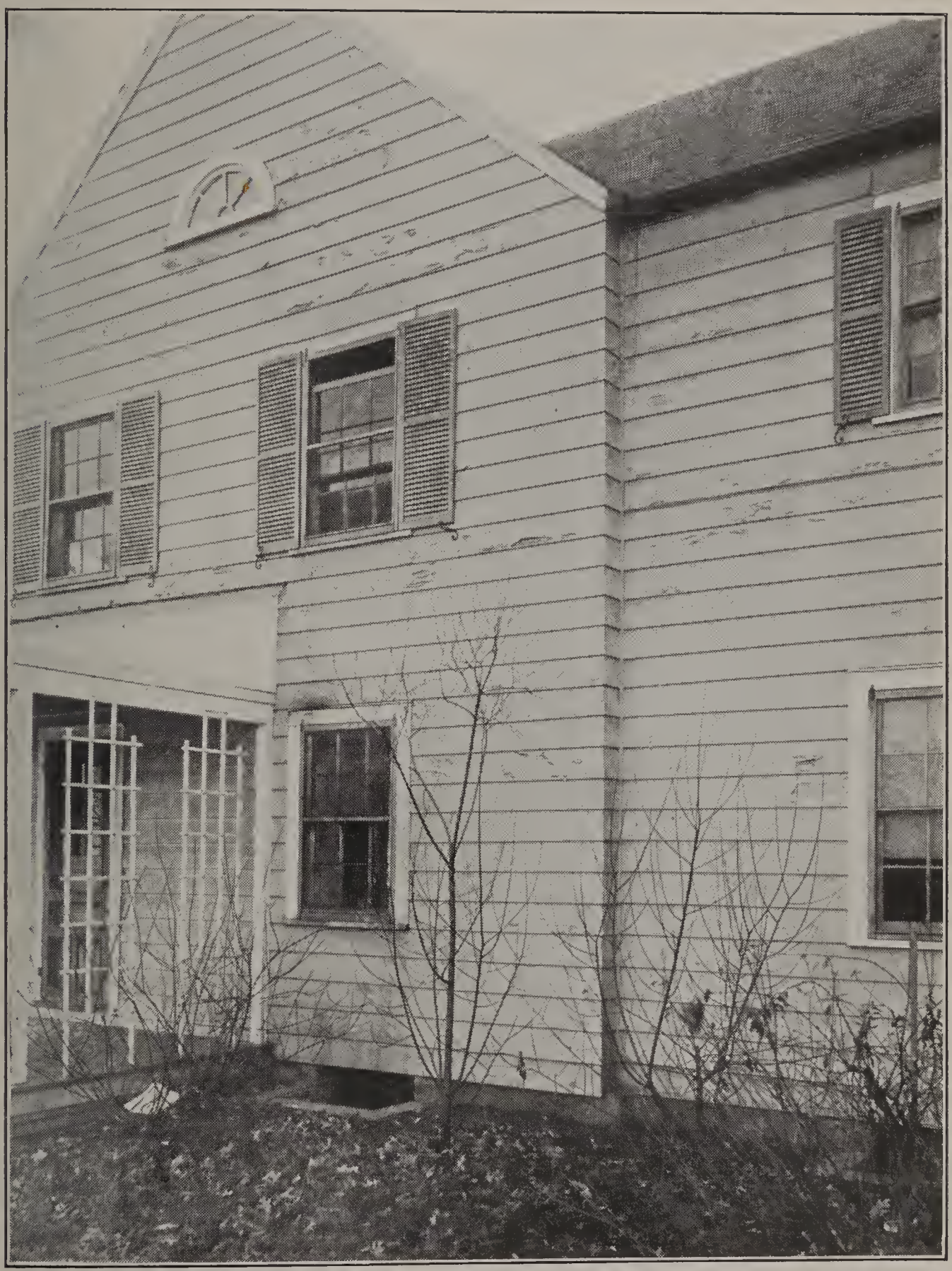
In the maintenance of a paint over a long period it is advantageous to adhere to one type of paint, at least for all paintings after the first one. Changing the type of paint at each time of painting builds up a coating of varying composition with the danger that unpredictable vagaries in behavior may be encountered.

BLISTERING OF COATINGS

Conditions sometimes arise under which paint coatings on wood buildings do not undergo the normal course of deterioration already described but fail in an unreasonably short time by blistering followed by peeling or by scaling of the coating, generally in large patches, or else become discolored by exudation of water-soluble dyes contained in the wood or by blue stain fungi growing in sapwood (Browne, fifth reference, and Hartwig). Practically speaking, moisture gaining access to the backs of the painted boards is invariably the cause of such abnormal paint behavior (pl. 5). The quality of the paint, the workmanship during application, and the nature of the wood are not directly responsible for abnormal behavior because under such circumstances all paints fail and trouble may be expected on any kind of wood.

There is only one remedy for abnormal paint behavior of this type, namely, location of the source of the moisture and improvement of conditions to eliminate it.

Moisture may gain entrance to the side walls of buildings in several ways, among which the most important are (1) by seepage of



The side walls of this house become wet every winter and by spring the boards of siding are thoroughly wet and cause scaling of paint. The house was painted in March of one year, repainted in July the next year, and photographed the following year.

rain water or melting snow through joints and (2) by condensation from warm, moisture-laden air that originates within the building, circulates through hollow side walls, and is chilled when it meets the cold surfaces of sheathing or siding during cold weather. The following joints in frame buildings have frequently been found sources of seepage moisture: Junctions between the siding and corner boards, window and door casing, and chimney masonry; junctions between side walls and porch roofs; the junction between porch columns and plinth blocks; and leaking roofs, eave troughs, and down spouts. The following conditions have often caused condensation of moisture within painted side walls: Hastening the drying of plaster by heating without adequate ventilation; enclosing damp, stagnant air spaces under porches or parts of structures extending beyond the basement excavation; lack of ventilation in unused attics; failure to obtain a watertight basement; plumbing leaks; and artificial humidification or activities within the building that give off much moisture during cold weather.

BACK PRIMING AND MILL PRIMING

Concealed surfaces are sometimes painted to retard changes in the moisture content of the wood (Browne, fifteenth reference, and Edwards and Wray). More than one coat is rarely applied for such purposes, and using the same priming-coat paint that is applied to the exposed surfaces is often convenient. Siding, shingles, and millwork are the principal items of building lumber back primed in this way.

The practice of priming lumber and woodwork at the mill is increasing. One object of mill priming is to give protection against moisture during shipment, storage, and erection before final finishing is possible. Mill priming in general should include back priming where practicable because boards coated on one side are more likely to warp when the moisture content changes than uncoated boards or boards coated equally on all sides.

No coating that completely prevents changes in the moisture content of wood has been found; the best that can be done is to retard the rate of change (Hunt). Good coatings furnish adequate protection against rapidly changing atmospheric conditions or against alternate rain and sunshine, but they are relatively ineffective against prolonged exposure to extreme conditions and do not prevent seasonal fluctuations in the moisture content of interior woodwork.

Table 48 gives the comparative effectiveness of various common coatings in protecting wood at 11-percent moisture content against absorption of moisture during 2 weeks' exposure to nearly saturated air. Table 48 gives also the comparative effectiveness of 1, 2, and 3 coatings. These values are for the coatings when new. With age the effectiveness at first increases somewhat and then decreases as the coating deteriorates so that the coatings must be kept in good condition to maintain their effectiveness. A similar comparison of coatings for interior use only is given on page 246.

The degree of protection attainable with a priming coat alone is usually limited; at least 2 coats and often 3 are necessary to build up an adequate barrier against moisture (Browne, fifteenth ref-

erence). Mill priming, therefore, affords only a very moderate degree of protection against change in moisture content before installation, and after woodwork has been installed the benefit derived from back priming is probably limited.

Oils, resins, or waxes absorbed by the wood or forced into it by impregnation are much less effective against movement of moisture than good coatings that form a layer of substantial thickness over the wood.

TABLE 48.—*Moisture-excluding effectiveness of coatings, suitable for both exterior and interior use, during 2 weeks' exposure of wood (initially at 11-percent moisture content) to nearly saturated air*

[For ordinary exterior house paints in their customary uses moisture-excluding effectiveness greater than about 60 percent is not necessary. The data in this table should not be construed as an index of the serviceableness of such paints in general]

Coating no.	Description	Effectiveness [1] found for—		
		1 coat	2 coats	3 coats
		Percent	*Percent*	*Percent*
1	Aluminum powder in asphalt or pitch paint vehicle	----	----	98
2	Aluminum powder in no. 16 vehicle	39	88	95
3	Extra fine aluminum powder in no. 16 vehicle	78	92	94
4	Aluminum powder in "alkyd" type synthetic vehicle	15	81	93
5	White lead in a vehicle similar to no. 16	62	86	91
6	One coat of no. 2 plus 2 coats of no. 17	39	86	91
7	White lead in no. 19 vehicle	24	85	91
8	Aluminum powder in no. 23 vehicle	9	61	90
9	Asphalt or pitch paint	----	----	90
10	Aluminum powder in bodied linseed-oil vehicle	26	84	89
11	One coat of no. 8 plus 2 coats of no. 17	9	62	86
12	White lead in no. 23 vehicle	7	62	83
13	Aluminum powder in linseed oil	14	57	77
14	Aluminum powder and red lead in linseed oil	7	65	75
15	Linseed-oil house paint containing zinc oxide and other white pigments with or without tinting colors	30	69	73
16	Phenol-aldehyde synthetic resin, 50-gallon varnish [2]	5	49	73
17	Linseed-oil house paint containing no zinc oxide, such as common lead-and-oil paint	20	57	70
18	Red lead in linseed oil	4	58	64
19	Ester gum resin, 33-gallon spar varnish [2]	6	37	65
20	Graphite in linseed oil	4	58	64
21	Red linseed-oil barn paint, pigment 98 percent pure iron oxide	25	53	56
22	Red linseed-oil barn paint, pigment venetian red containing 40 percent iron oxide	1	25	45
23	Ester gum resin, 75-gallon long-oil spar varnish	3	14	35
24	Linseed oil containing paint drier	3	5	21

[1] Perfect protection would be represented by 100-percent effectiveness; complete lack of protection, as with uncoated wood, by zero.

[2] A "50-gallon" varnish is made in the proportion of 50 gallons of drying oil to 100 pounds of resin; a "33 gallon" varnish is made with 33 gallons of drying oil to 100 pounds of resin.

UNCOATED EXTERIOR WOODWORK

Architectural design sometimes calls for the appearance of weather-beaten wood, and the best way to attain such appearance is to let wood weather naturally, especially since uncoated exterior woodwork is not necessarily lacking in durability. For weathered construction it is advisable to choose woods that weather with a minimum of cupping, twisting, and conspicuous checking, ~~such as those of group 1 in table 45~~. Edge-grain boards weather better than flat-grain boards, and thick boards better than thin ones. It is also best to exclude boards containing pith and to place flat-grain boards with the bark side (~~the side nearer the bark of the log~~) out. Fastenings for wea-

thered construction should be secured especially firmly with noncorrosive metals, and joints should be designed to prevent retention of moisture as far as that is possible.

INTERIOR FINISHING

Interior finishing differs from exterior chiefly in that interior woodwork usually requires much less adequate protection against moisture and that more exacting standards of appearance and a greater variety of effects are expected (~~Browne, second reference~~). Good interior finishes should last much longer than exterior paint coatings, but no interior finish should ever be used out of doors.

OPAQUE FINISHES

Interior surfaces may, if desired, be painted with the materials and by following the procedures recommended for exterior surfaces. As a rule, however, smoother surfaces, better color, and a more lasting sheen are demanded for interior woodwork, and therefore enamels rather than paints are employed. These finishes differ from paints in that linseed oil is replaced partly or entirely by bodied oils or by varnishes in order to make a coating that does not show brush marks and presents a harder surface with a desired degree of gloss. They may also be made of nitrocellulose lacquers or synthetic resins and drying oils that dry much more rapidly than oleo-resinous enamels. Unless made with expensive pigments of extraordinary opacity, such as titanium dioxide or zinc sulphide, enamels are less opaque than paints of the same color because they cannot be made with so large a proportion of pigment.

Before enameling, the wood surface must be made extremely smooth. Imperfections, such as planer marks, hammer marks, and raised grain, are accentuated by enamel finish. Raised grain is especially troublesome on flat-grain surfaces of the heavier softwoods because the hard bands of summer wood are sometimes crushed into the soft spring wood in planing and later are pushed up again when the wood changes in moisture content (~~Koehler~~). It is helpful to sponge softwoods with water, allow them to dry thoroughly, and then sandpaper them lightly with sharp sandpaper before enameling. In new buildings woodwork should be allowed adequate time to come to its equilibrium moisture content before finishing.

Hardwoods having large pores must be filled with wood filler before the priming coat. For all woods the priming coat may be white-lead paint mixed according to directions for exterior priming-coat paint, or special priming paints made for that purpose may be used. Knots in the white pines, ponderosa pine, or southern yellow pine should be shellacked after the priming coat is dry. A coat of shellac is sometimes necessary also over the white pines and ponderosa pine to prevent discoloration of light-colored enamels by colored matter apparently present in the resin of the heartwood of these species. One or two coats of enamel undercoat are next applied; this should completely hide the wood and should also present a surface that can easily be sandpapered smooth. For best results the surface should be sandpapered before applying the finishing enamel, but this operation is sometimes omitted. After the finishing enamel has been applied it may be left with its natural gloss or rubbed to a dull finish.

TRANSPARENT FINISHES

There are many good ways of applying transparent finishes to either hardwoods or softwoods. Most finishing consists in some combination of the following fundamental operations: Staining, filling, sealing, surface coating, rubbing, and polishing. Before finishing, planer marks and other blemishes of the wood surface that would be accentuated by the finish must be removed.

Both softwoods and hardwoods are often finished without staining, especially if the wood is one with a pleasing and characteristic color. When used, however, stain often provides much more than color alone because it is absorbed unequally by different parts of the wood and therefore accentuates the natural variations in grain. With hardwoods such emphasis of the grain is usually desirable; the best stains for the purpose are dyes dissolved either in water or in oil. The water stains give the most pleasing results but raise the grain of the wood and require an extra sanding operation after the stain is dry. "Non-grain-raising" stains are now available that often approach the water stains in clearness and uniformity of color. With softwoods, stains color the spring wood more strongly than the summer wood, reversing the natural gradation in color in a manner that is often garish. Pigment-oil stains, which are essentially thin paints, are less subject to this objection than are other stains and are therefore more suitable for softwoods.

Hardwoods having large pores must be filled before a smooth varnish or lacquer coating can be applied. If a smooth coating is not desired, however, filling is optional. The filler may be transparent and without effect on the color of the finish or it may be colored to contrast with the surrounding wood. Usually colored filler is darker than the rest of the wood.

Sealer is used to prevent absorption of subsequent surface coatings and to prevent the bleeding of some stains and fillers into surface coatings, especially lacquer coatings. Shellac is the oldest type of sealer. Varnish can be used as a sealer but is not so effective as shellac.

Surface coatings may be of wax, shellac, varnish, or nitrocellulose lacquer. Wax provides a characteristic sheen without forming a coating of sensible thickness and without greatly enhancing the natural luster of the wood. Coatings of a more resinous nature, especially shellac and varnish, accentuate the natural luster of some hardwoods and seem to permit the observer to look down into the wood to a certain extent. Shellac applied by the laborious process of French polishing probably achieves this impression of depth most fully, but the coating is easily marred by water and is expensive. Rubbing varnishes made with resins of high refractive index for light are nearly as effective as shellac. Lacquers have the advantage of drying rapidly and forming a hard surface but require more applications than varnish to build a lustrous coating.

Varnish and lacquer usually dry with a highly glossy surface. To reduce the gloss the surfaces may be rubbed with pumice stone and water or polishing oil. Waterproof sandpaper and water may be used instead of pumice stone. The final sheen varies with the fineness of the powdered pumice stone, coarse powders making a dull surface and fine powders a bright sheen. For very smooth surfaces with high

polish the final rubbing is done with rottenstone and oil. Varnish and lacquer can be made to dry dull in the first place, but the result is not quite the same as that produced by rubbing.

FINISHES FOR FLOORS

Finishes for wood floors are subject to severe mechanical wear and consequently deteriorate more rapidly than finishes on most other classes of woodwork. Floor finishes must, therefore, be renewed frequently. Discussions of floor finishes usually place undue emphasis upon the kind or quality of material used and pay far too little attention to the maintenance. Any of the common types of floor finishes will keep wood floors in excellent condition if properly maintained, but no finish will do so if it is neglected. The essential problem is to adapt a systematic program of maintenance to the requirements of the finishing material chosen and of the degree of wear to which the floor is subjected.

The opaque and transparent interior finishes already described are applicable to floor finishing, provided that the floor paints, floor varnishes, or lacquers are made with the careful balance between toughness and hardness necessary to make them resistant to mechanical wear. The essential point in maintaining any floor finish that includes a surface coating is to recoat before the old coating has actually worn down to the wood in conspicuous spots. Good floor paints or varnishes require less frequent renewal than wax finishes under similar conditions of wear, but each renewal is more expensive in material and labor and keeps the floor from being used for a longer time than finishes that do not include substantial surface coating. For floors subject to heavy wear, coatings of any kind often prove unduly expensive and inconvenient.

Floors subject to heavy wear are often finished with floor oils that are absorbed by the wood and do not form substantial coatings. They furnish less adequate protection against moisture and dirt than coatings, but are cheaper and can be applied with less labor and inconvenience. Most floor oils darken wood appreciably and do not present so fine an appearance as well-maintained coatings. A new method is coming into use that keeps oiled floors bright and clean by buffing them with steel wool after oiling, and at suitable intervals. Machines for buffing floors with steel wool are now available.

Floor waxes applied either directly to wood or over a sealer do not form substantial coatings. They are usually superior to floor oils in appearance although they must be renewed even more frequently. Floor waxes of the emulsion type are very quickly and easily applied and are relatively inexpensive.

EFFECTIVENESS OF MOISTURE-EXCLUDING COATINGS SUITABLE FOR INTERIOR USE

The comparative effectiveness of various common coatings in protecting wood at 11-percent moisture content against absorption of moisture during 2 weeks' exposure to nearly saturated air is given in the following tabulation in which perfect protection would be represented by 100-percent effectiveness; complete lack of protection, as with uncoated wood, by zero. A similar comparison of coatings for exterior use is given on page 242.

Description:	*Percent effectiveness*
3 coats of spar varnish coated with vaseline (for storage purposes only)	98
Aluminum-leaf process, cellulose-lacquer base	94
3 coats of aluminum powder in gloss oil (quick drying)	92
3 coats of aluminum powder in shellac	92
Heavy coating of paraffin	91
3 coats of rubbing varnish	89
3 coats of shellac	87
3 coats of enamel (cellulose-lacquer vehicle)	76
3 coats of cellulose lacquer	73
3 coats of gloss oil bronzing liquid	12
3 coats of furniture wax	8

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PROTECTION AGAINST WOOD-DESTROYING ORGANISMS

MOLD, STAIN, AND DECAY

Generally speaking, molds, stain, or decay appearing in lumber may be traced to lack of proper precautions in yarding logs and in piling, storing, and handling sawed material. The problems of fungous attack in milling and merchandising stages have been extensively studied by Government and other investigators, and preventive measures are well known and widely practiced in the industry. The present market trend indicates that in the future very little, if any, stain, and certainly no decay, will be tolerated in lumber except in the lowest grades. It remains for the user to build with his material in such a way as to insure the structure against the inception and spread of decay—in other words, not to expose wood to unnecessary hazards. Under proper conditions, wood has proved itself good for centuries of service.

Molds, stains, and decays in wood are caused by fungi, which are microscopic plants that must have organic material on which to live, and for some of them wood offers the required food supply. Their growth, however, is dependent upon suitable surroundings of mild temperature and dampness, the latter being aggravated by sluggish circulation of air. Most decay occurs in wood having moisture above the fiber-saturation point. Wood that is continuously water-soaked or continuously dry (below 20-percent moisture) will not decay.

MOLDS AND STAINS

Molds and stains, which are confined largely to the sapwood, are characterized by cottony or powdery surface growths of various colors. Little direct staining of the wood is caused by molds, since the discoloration caused by them is largely superficial and is due for the most part to a surface growth, which varies from white or light colors to black. Such blemishes are easily brushed or surfaced off.

Stains penetrate into the sapwood (not heartwood) and cannot be removed by surfacing. The discoloration of the wood occurs as specks, spots, streaks, or patches of varying intensities of color. The so-called " blue " stains, which vary from bluish to bluish-black and brown, are the most common, although various shades of yellow, orange, purple, and red are sometimes encountered, the exact color depending on the infecting organism and the species and moisture condition of the wood. The brown stain mentioned should not be confused with chemical brown stain (p. 8). Under improper moisture and temperature conditions staining and molding fungi may become established and develop rapidly in the sapwood of wood products shortly after they are cut. In addition, lumber and such products as veneer, furniture stock, vehicle stock, airplane stock

(Boyce),[35] and sash may become infected at any stage of manufacture or subsequent use if exposed to unfavorable moisture conditions. Freshly cut or unseasoned stock that is piled during warm, humid weather may be noticeably discolored within 5 or 6 days. (See p. 205 for recommended control measures.)

Effect on Wood

Stains should not be considered a stage of decay, since staining fungi do not attack the wood substance appreciably. Ordinarily, they affect the strength of the wood only slightly, and further the effect is usually confined to those strength properties that determine shock resistance (p. 66).

Blue-stained stock is practically unimpaired for many uses in which appearance is not a limiting factor and in which conditions permit the use of sapwood. It is not entirely satisfactory for window sash, however. If the sash becomes sufficiently wet the staining fungi may grow, breaking through the paint and thus making the sash unsightly.

DECAY

Decay-producing or wood-destroying fungi may, under conditions that favor their growth, attack either heartwood or sapwood, causing a condition of the wood that is variously designated as decay, rot, or dote. The fresh surface growths of decay fungi are usually fluffy or cottony, and only seldom powdery as the molds are. They may appear as fan-shaped patches, strands, or rootlike structures, usually white or brown. The occurrence of fruiting bodies, which take the form of toadstools, brackets, or crusts, is evidence of interior disintegration of the wood. The microscopic strands or hyphae that permeate the wood use portions of the wood itself as food. Some wood-destroying fungi live largely on the cellulose whereas others use the lignin more than the cellulose.

The early or incipient stages of decay are often accompanied by a discoloration of the wood, which is more evident on freshly exposed surfaces of unseasoned wood than on dry wood. In the case of many fungi the variation from the normal color of the wood in the incipient stage of decay is very slight or marked by a somewhat water-soaked appearance of the wood.

Typical or late stages of decay are easily recognized because the wood has then undergone definite changes in color and properties, which depend upon the causative organism and the substances it removes. The rotted wood may be white or brown in color, white if the decay fungus consumes lignin more than cellulose and brown if the reverse is the case. There are also intermediate types between the white and brown rots.

Every brown, crumbly rot is commonly called "dry rot", but since no wood will rot while it is dry, the term "dry rot" is a misnomer. There are a few fungi that have water-conducting strands and are therefore capable of carrying water from some source, usually in the soil, up into buildings or lumber piles, where they moisten and rot wood that would otherwise be dry. After these fungi cease to

[35] For further information, the references at the end of this section should be consulted.

work, the decayed wood commonly becomes dry again; the term "dry rot", if used at all, is probably best limited to the work of these fungi. Many other fungi produce typical brown, crumbly rots (Hoxie, and Snell), and some of them can work in wood having comparatively little free moisture, but in no case does really dry wood rot.

Occurrence

Certain wood-destroying fungi attack the heartwood, and rarely the sapwood, of living trees, whereas others confine their activities to logs or manufactured products, such as sawed lumber, structural timbers, poles, and ties. A few of the first group may cease their activities after the trees have been cut, as in pecky cypress or pecky incense cedar. Others may continue their destruction after the trees have been cut and worked into products, provided conditions are favorable for their growth. In living trees the sapwood is less subject to attack than the heartwood. The sapwood of logs or products, on the other hand, decays more readily than the heartwood; this may be due to the more available food supply in the sapwood, or to the presence in the heartwood of certain extractives that are toxic to the fungus.

Decay Resistance of Woods

For a discussion of the natural resistance of wood to wood-destroying fungi, and a list of species in relative order of durability, see page 41.

Effect on Strength of Wood

Incipient decay induced by some fungi is reflected immediately in pronounced weakening of the wood, whereas other fungi produce only slight reduction in strength (p. 66). For example, the decay produced by *Trametes pini*, commonly called "red heart", causes little or no reduction in strength in its incipient stage. This is the most common decay in the softwoods. On the other hand, *Polyporus schweinitzii*, another common rot in softwoods, greatly reduces the strength of wood at a very early stage. In the later stages of decay any wood-destroying fungus will cause a serious reduction in strength.

CONTROL OF MOLDS, STAINS, AND DECAY

Logs, Poles, Piling, or Hewed Ties

Rapid surface seasoning of poles, piling, ties, and similar products by first peeling and then decking on high skids or piling on high, well-drained ground in the sun will retard the development of molds, stains, and decay, but checking must be guarded against. The species, section of the country, and time of the year will determine what precautions must be taken to avoid excessive checking and still get rapid enough seasoning to avoid early damage from fungi.

Antiseptic sprays and coatings applied to the ends and barked portions of logs are effective for normal storage periods provided wood-infesting insects are not too prevalent (Lindgren, Scheffer, and Chapman, second reference; and Teesdale).

Lumber

Fungous defects in lumber and other wood products may be prevented by quickly reducing the moisture content below 20 percent and by keeping the wood dry. Treating freshly cut lumber with antiseptic solutions will prevent fungous infection during seasoning; successful control by this method depends not only upon adequate treating practices but also upon the proper subsequent handling of the material (Humphrey, first reference; and Lindgren, Scheffer, and Chapman, first reference).

Kiln drying lumber green from the saw is the most satisfactory and effective method of rapidly reducing the moisture content. It is used principally by the larger mills for the high grades of softwoods but offers promise of increased application in the hardwood and small softwood mills.

Air-seasoning yards and sheds should be kept in as sanitary a condition as possible. Recommended practice includes location on well-drained ground; the removal of debris, which serves as a source of infection, and the cutting of weeds, which reduce air circulation; keeping sheds dry and well aired; and employing proper piling methods, which permit rapid drying of the lumber. Proper piling requires high, sloping foundations, the avoidance of close or solid piling of unseasoned stock, tight roofs raised above the top courses, and the use of sound, dry, and well-manufactured stickers of heartwood of decay-resistant species or of chemically treated wood.

The user's best assurance of receiving lumber free from decay or stain is to deal with yards or mills that follow good seasoning practice. If lumber is to be used under conditions conducive to decay, it should be the heartwood of a naturally durable species or should be adequately treated with a good wood preservative (p. 263).

Buildings

In order to avoid decay in buildings, the following points should be carefully considered when building or when making repairs due to decay (Humphrey, second reference; Humphrey and Miles; and Richards):

The use of unseasoned and infected wood should be avoided in construction. Unseasoned and infected wood may result from improper handling at the sawmill, retail yard, or after delivery on the job.

Since moisture in wood is essential to its decay, buildings should be designed to avoid the possibility of the wood becoming damp enough to decay. Where service conditions are such that the wood cannot be kept dry, as for example in floors that must frequently be damp or in the roof planking of textile and dye houses, lumber of high natural decay resistance or treated lumber should be used [36] (Hoxie).

Foundation timbers, posts, steps, porches, or other wood parts of a building should not be placed in contact with the soil unless of treated wood or the heartwood of a naturally durable species.

If ventilation sufficient to keep the wood dry cannot be provided, the use of treated wood or the heartwood of a naturally durable species is advisable for the ground floor.

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[36] Hunt, G. M. Factors that influence the decay of untreated wood in service. U. S. Dept. Agr., Forest Serv. Forest Products Lab. R68, 5 pp. 1931. [Mimeographed.]

Wood concrete forms, stakes, wood debris, or old stumps left under a building are often directly responsible for decay in the building. Care should be taken that they are removed.

When wood flooring must be laid over concrete through which it can absorb moisture from the ground it should be protected with a preservative. In dry locations it is especially important that fresh concrete be thoroughly dried before wood floors are laid over it.

Leaks in roofs, around doors and windows, and in plumbing may supply moisture enough to cause growth of decay organisms. Such leaks should be prevented or repaired immediately.

In cold weather, condensation water may accumulate in the lower rails of window sash, providing favorable conditions for the growth of staining and decay-producing fungi. The use of storm windows reduces the amount of condensation and is largely effective in controlling the stain and decay. Insurance against this trouble can also be provided by the use of durable heartwood or preservatively treated lumber.[37]

In making repairs in a building in which the conditions leading to decay cannot be corrected, all infected parts should be replaced with naturally durable wood or with treated wood (Hunt). It is advisable to remove the material at least 2 feet beyond any evidence of decay, for the fungus threads extend for a distance in advance of visible decay. Removal of all infected wood and the use of treated or highly durable wood in replacements may not be necessary if the design can be so changed as to make it impossible for the old or new wood to remaian sufficiently moist for decay development.

INSECTS

The more common defects in timber caused by insects [38] are shown in table 49 (Snyder, second reference). The insects shown as inhabiting logs and recently felled trees can continue their work in log structures, especially if the bark is left on. The powderpost beetles are the only ones shown in the table that may do serious damage after the logs are cut into lumber or timbers and seasoned.

BEETLES

Bark beetles (St. George) may damage log structures and other rustic construction where the bark is left on. They are reddish-brown to black insects varying in length from about one-sixteenth to one-fourth inch that bore through the outer bark to the soft inner portion, where they make tunnels of various types along which they lay their eggs. In making the tunnels they push out fine brownish-white, sawdustlike particles which betray their presence under the bark. If many beetles are present the extensive tunneling will loosen the bark and permit it to fall off in time in large patches, making the structure unsightly.

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[37] HUNT, G. M. DECAY RESISTANCE IN WOODS FOR WINDOW SASH AND FRAMES. U. S. Dept. Agr., Forest Serv. Forest Products Lab. R919, 10 pp. 1933. [Mimeographed.]

[38] The U. S. Bureau of Entomology and Plant Quarantine at Washington, D. C., specializes in the study of insect habits and methods of control. Inquiries relating to these subjects should generally be addressed to that Bureau. In California inquiries about termites may be sent to the termite investigations committee, University of California, Berkeley.

TABLE 49.—*Classification of the more common defects in timber caused by insects*

Type of defect	Description	How and when made	Condition of defective timber
Pinholes	Holes with dark streak in surrounding wood:		
	Hardwoods:		
	Stained area 1 inch or more long.	By ambrosia beetles in living tree.	Wormholes, no living worms or decay.
	Stained area less than 1 inch long.	By ambrosia beetles in recently felled trees and green logs.	Do.
	Softwoods	By ambrosia beetles in sapwood of felled trees, logs, or green lumber.	Do.
Grub holes	Holes alone darkly stained:		
	Larger than ⅛ inch in diameter.	By wood-boring grubs in living trees.	Do.
	Smaller than ⅛ inch in diameter.	By ambrosia beetles in felled trees, green logs, or green lumber.	Do.
	Holes unstained:		
	Holes circular, open:		
	Holes less than ⅛ inch in diameter.	By ambrosia beetles in recently felled green logs or green lumber.	Do.
	Holes more than ⅛ to ¼ inch in diameter.	By timber worms in living trees.	Do.
	Holes oval, with powder-like boring dust or shreds (frass); usually more than ¼ inch in diameter.	By round-headed borers in recently felled softwoods and hardwoods.	Do.
Powderpost [1]	Holes unstained, filled with granular or powdery boring dust:		
	Hardwoods	By round-headed borers and powderpost beetles in green or seasoned timber.	Wormholes, no living worms or decay, or powderpost.
	Softwoods:		
	Boring dust tightly packed (pellets of digested and excreted wood).	By flat-headed borers in living or green felled trees.	Do.
	Boring dust shredded, loose.	By round-headed borers in seasoned wood.	Do.
Pitch pocket		By various insects in living trees.	Wormholes, no living worms or decay.
Black check		By the grubs of various insects in living trees.	Do.
Bluing	Stained area over 1 inch long	By fungus following insect wounds in living trees and recently felled sawlogs.	Do.
Pitch fleck		By the maggots of flies or adult weevils in living trees.	Do.
Gum spot		By the grubs of various insects in living trees.	Do.
Ring distortions		By defoliating larvae	Do.

[1] Powderpost or living wormy is a continuous injury, hence timber having this defect cannot be used with safety before treatment with chemicals, kiln drying, or steaming in a kiln. This defect can be prevented by proper handling of the stock.

To avoid bark-beetle damage the logs should be cut in October or November and piled at once off the ground in the open or under cover in such a manner as to offer the best facilities for the rapid drying of the inner bark before the beetles begin to fly in the spring. This will in almost every case prevent damage by insects that prefer freshly cut wood. When the logs cannot be cut or handled as recommended, it is advisable to immerse them in a mixture containing 1 part of coal-tar creosote and 3 parts of kerosene.

Ambrosia beetles, round-headed borers, and some powderpost beetles (St. George; and Snyder, second reference) that get into freshly cut timber can cause considerable damage to wood in rustic

structures. Cutting the timber in October and November and seasoning, as just mentioned, will control the ambrosia beetles but not always the powderpost or round-headed borers. Maximum protection may be obtained by the additional precaution of dipping the logs thoroughly in the creosote-kerosene mixture in spring, before the first flight of the insects.

Powderpost beetles (St. George; and Snyder, first and second references) attack hardwoods, both in the freshly cut timber and in seasoned lumber and timbers. The powderpost beetles that do most damage to dry lumber are those belonging to the *Lyctus* species. They damage only the seasoned sapwood of hardwoods. Ash, hickory, and oak principally are affected; other hardwoods, including walnut, maple, persimmon, cherry, elm, poplar, and sycamore, are affected to a lesser extent. They are especially likely to attack hardwood lumber and products that are left undisturbed in storage for long periods. Eggs are laid in the pores of the wood, and the larvae burrow through the wood, making holes about one-sixteenth to one-twelfth inch in diameter, which they leave packed with a fine powder. The presence of powderpost damage is indicated by holes left in the surface of the wood as the larvae become winged adults and emerge and also by the fine powder that may fall from the wood.

When selecting hardwood lumber for building purposes, any evidence of powderpost infestation should not be overlooked, for the beetles may continue their activities after the lumber is in use. Sterilization with steam at not less than 130° F. or in a dry kiln at 180° for 1½ hours is effective in inch lumber. Thicker material requires longer time. Thorough application of kerosene or a mixture of 3 parts kerosene and 1 part coal-tar creosote is a good remedy where the use of these materials is practicable. In case of powderposting of furniture or lumber installed in a building, swabbing thoroughly with orthodichlorobenzene is recommended. Since the beetles lay their eggs in the open pores of the wood, painted or varnished surfaces are immune to infestation. If some of the surfaces are left unfinished, however, as is usually the case, attack may begin at these places. Care is necessary in applying orthodichlorobenzene to avoid burning the skin of the operator and especially to avoid getting the chemical into his eyes.

Stocks of susceptible hardwoods should not be allowed to remain in manufacturing plants or warehouses undisturbed for long periods but should be kept moving if possible. Piling strips or stickers, if reused repeatedly, should be of heartwood or of some species that is not subject to *Lyctus* beetle attack. All waste wood and debris on the premises should be kept cleaned up. Frequent inspections should be made, and all infested pieces should be treated by immersing in kerosene or creosote-kerosene mixture or sterilized by heat, or else burned. Treating with boiled linseed oil, hardened gloss oil, or any material that will plug up the pores and leave a substantial coating over the surface will prevent attack.

TERMITES

Termites (Kofoid et al.; Light; and Snyder, third and fourth references) superficially resemble ants in size, general appearance, and habit of living in colonies, hence they are frequently called "white

ants." About 56 species of termites are known in the United States, and hundreds more in other countries. From the standpoint of their methods of attack on wood the termites of the United States can be grouped into two main classes: (1) The ground-inhabiting or subterranean termites; and (2) the dry-wood termites. Subterranean termites are found in nearly every State and are responsible for most of the termite damage to wood structures. Dry-wood termites are found only in a narrow strip of territory extending from central California around the southern edge of the United States to Virginia. Figure 63, prepared by the United States Bureau of Entomology and Plant Quarantine (Snyder, third reference) shows the approximate range of each group.

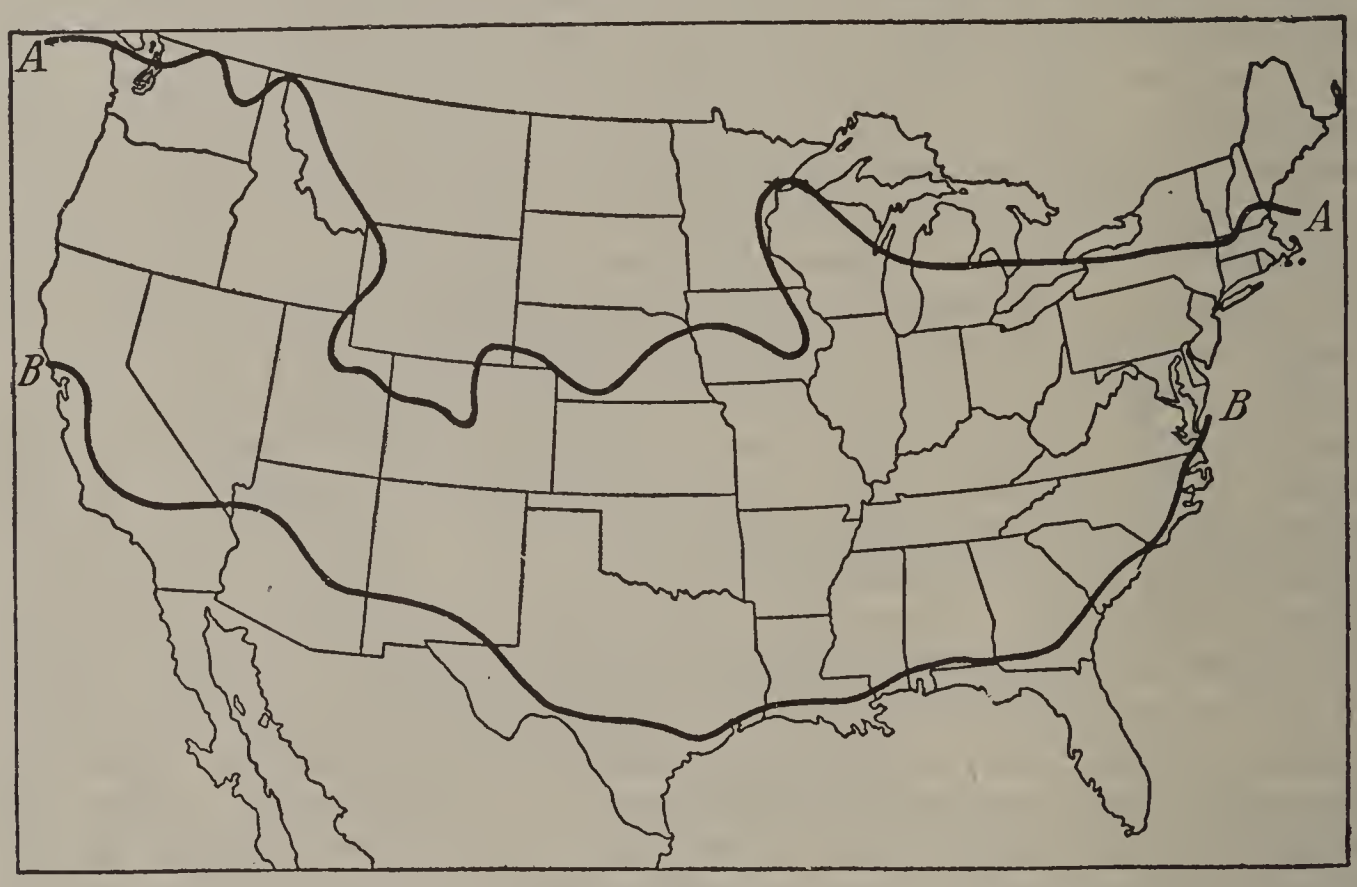


FIGURE 63.—Distribution of termites in the United States. Subterranean termites are found south of the line *AA*, dry-wood termites south of the line *BB*.

The subterranean termites develop their colonies and maintain their headquarters in the ground, from which they build their tunnels through earth and around obstructions to get at the wood they need for food. Each colony shuts itself off and lives in the dark. These termites must have a constant source from which to obtain moisture or they will die. It is the worker members of the colony that cause the destruction of wood. At certain seasons of the year male and female winged forms swarm from the colony, fly a short time, lose their wings, mate, and if successful in locating a suitable place they start new colonies. The appearance of "flying ants" is an indication that a termite colony is near and perhaps causing serious damage unnoticed. Subterranean termites do not establish themselves in buildings by being carried in in lumber but by entering from ground nests after the building has been constructed. If unmolested, they eat out the wood work, leaving a shell of sound wood to conceal their activities. The damage may proceed so far as to cause collapse of portions of the structure before discovery.

The nonsubterranean or dry-wood termites are fewer in numbers, do not multiply so rapidly, and have colony life and habits somewhat different from those of the subterranean termites. The total amount of destruction they cause in the United States is very much less than that caused by the subterranean termites. Their ability to live in dry wood without outside moisture or contact with the ground, however, makes them a definite menace in the regions where they occur. Their depredations are not rapid, but they can thoroughly riddle timbers with their tunnelings if allowed to work unmolested for a few years.

Only a limited number of woods grown in the United States offer any marked degree of resistance to termite attack. California redwood and southern cypress have some resistance, especially where used aboveground, but termites are known to attack them at times. Very resinous heartwood from southern pine is practically immune, but wood of this character is not available in large quantities or suitable for many uses.

The best protection where subterranean termites are prevalent is to build so as to prevent their gaining access to the building (Kofoid et al.; and Snyder, third reference). The foundations should be of concrete or other solid material through which the termites cannot penetrate. With brick, stone, or concrete blocks, cement mortar should be used, for termites can work through some other kinds of mortar. Wood that is not impregnated with an effective preservative must be kept well away from the ground. If there is a basement, it should preferably be floored with concrete. Posts that support the first-floor beams must not rest directly on the ground or on wood blocking unless thoroughly treated. They should preferably rest on concrete piers extending a few inches above the basement floor if that floor is of concrete; if the basement floor is of earth, the concrete piers should extend at least 18 inches above it. If the earth is not excavated beneath the building, the floor beams and other woodwork, unless adequately treated with preservative should be kept at least 2 feet from the earth and good ventilation beneath the floor should be provided. All concrete forms, stumps, waste wood, and the like should of course be removed from the building site. Stakes left embedded in concrete or beside concrete foundations afford easy means for termites to enter buildings and should be sought out and removed. In the main the precautions that are effective against subterranean termites are also helpful against decay.

Termite shields (Snyder, third reference) should be placed between foundation and woodwork. These are sheets of metal that extend out from the foundation at an angle of 45° for a horizontal distance of at least 2 inches. They prevent the termites from extending their tubes over the foundation to reach the sills. Similarly, metal shields should be fitted tightly around water and sewer pipes, electrical conduit, or any similar equipment along which termites could build their tubes and gain entrance to woodwork.

If a building has become infested with ground-nesting termites, the infested wood should be replaced, preferably with treated wood, the precautions suggested above for new buildings should be put into effect, the entrance galleries of the termites and, if possible, the nest should be searched out and destroyed. All waste wood of any kind should be removed from the vicinity of the building.

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In constructing a building in localities where the dry-wood termites are prevalent, it is well to inspect the lumber carefully to see that it has not become infested before arrival at the building site. If the building is constructed during the swarming season, the lumber should be watched during the course of construction, since infestation by colonizing pairs can easily take place at this season (Light). Since paint is a good protection against the entrance of dry-wood termites, all exposed wood should be kept adequately painted. Fine screen should be placed over any openings through which access might be gained to the interior unpainted parts of the building. As in the case of ground-nesting termites, old stumps, posts, or wood debris of any kind that could serve as sources of infestation should be removed from the premises.

If a building is found to be infested with dry-wood termites, the infested wood should be replaced if badly damaged. If only slightly damaged or difficult to replace, further activity may be arrested by blowing poisonous dust, such as finely divided paris green, arsenical dust, or sodium fluosilicate, into each nest.

In localities where dry-wood termites do serious damage to posts and poles, the best protection for these and similar forms of outdoor timbers is a full-length treatment with coal-tar creosote or other good preservative.

Considerable publicity has been given in recent years to termites and their activities. In some localities "termite experts", often having very little knowledge of the subject, have developed considerable business in eradicating termites from buildings. It is well to investigate the qualifications of such persons thoroughly before investing any money in their services. The help of a real expert can be of great value, but the claims of many have been found to be fraudulent.

CARPENTER ANTS

Carpenter ants are large or small black or brown ants that are found usually in stumps, trees, or logs, but sometimes are found doing damage in poles, structural timbers, or buildings. They use the wood for shelter rather than for food, usually preferring wood that is naturally soft or has been made soft by decay. They may enter a building directly, by crawling, or may be carried in in fuel wood. If left undisturbed they can in a few years enlarge their galleries to the point where replacement or extensive repairs are necessary.

Precautions that prevent attack by decay and termites are usually effective against ants. Decaying or infested wood, such as logs or stumps, should be removed from the premises.

When carpenter ants are found in a structure, badly damaged timbers should be replaced. In timbers not sufficiently damaged to require replacement, the ants can be killed by swabbing the affected parts with a rag saturated with orthodichlorobenzene. Several applications may be necessary. If there are holes through which the ants are extruding wood dust, it is desirable to inject orthodichlorobenzene or carbon disulphide (Hinds) into the holes and then seal them with mud, putty, or some other suitable material. Carbon disulphide should be used with due caution, in view of its well-known inflammable and toxic character.

MARINE BORERS

Damage by marine boring organisms to fixed or floating structures of wood in salt or brackish waters is practically world-wide and has called forth all the protective measures known to man from ancient times to the present. Slight attack is sometimes found in rivers even above the region of brackishness. The rapidity of attack depends upon local conditions and the kinds of borers present. Along the Pacific, Gulf, and South Atlantic coasts of the United States attack is rapid, and untreated piling may be completely destroyed in a year or less. Along the coast of the New England States the rate of attack is less rapid but still sufficiently rapid generally to require protection of wood where long life is desired.

The principal marine borers from the standpoint of wood destruction in the United States are (Atwood and Johnson; Calman; and Hill and Kofoid) described in the following paragraphs.

SHIPWORMS

Shipworms are mollusks of various species that superficially are wormlike in form. The group includes several species of *Teredo* and several species of *Bankia* that are readily distinguishable on close observation but are all very similar in several respects. In the early stages of their life they are minute, free-swimming organisms. Upon finding suitable lodgement on wood they quickly develop into a new form and bury themselves in the wood. A pair of boring shells on the head grows rapidly in size as the boring progresses, while the tail part or siphon remains at the original entrance. Thus the animal grows in length and diameter within the wood but remains a prisoner in its burrow, which it lines with a shell-like deposit. It lives upon the wood borings and upon the organic matter extracted from the sea water that is continuously being pumped through its system. The entrance holes never grow large, and the interior of a pile may be completely honeycombed and ruined while the surface shows only slight perforations. When present in great numbers the borers grow only a few inches before the wood is so completely occupied that growth is stopped, but when not crowded they can grow to lengths of 1 to 4 feet according to species.

LIMNORIA

Limnoria are small crustaceans about one-eighth to one-sixth inch long that bore small burrows in the surface of piling. They can move freely from place to place if occasion requires but usually continue to bore in one place. When great numbers are present their burrows are separated by very thin walls of wood that are easily eroded by the motion of the water and objects floating upon it. This erosion causes the animals to burrow continually deeper; otherwise the burrows would probably not become more than 2 inches long or more than one-half inch deep. Since erosion is greatest between tide levels, piling heavily attacked by *Limnoria* characteristically wears within such levels to an hour-glass shape. Untreated piling can be destroyed by *Limnoria* within a year in heavily infested harbors.

MARTESIA

Martesia are wood-boring mollusks that resemble clams in general appearance. Like the shipworms, they enter the wood when very

small, leaving a small entrance hole, but grow larger as they burrow into the wood. They generally do not exceed 2½ inches in length and 1 inch in diameter but are capable of doing considerable damage. Their activities in the United States appear to be confined to the Gulf of Mexico.

SPHAEROMA

Sphaeroma are somewhat similar to *Limnoria* but larger, sometimes reaching a length of one-half inch and a width of one-fourth inch. They resemble in general appearance and size the common sow bug or pill bug that inhabits damp places. They are widely distributed but not so plentiful as *Limnoria* and do much less damage. Nevertheless piling in some structures has been ruined by them. Occasionally they have been found working in fresh water.

RESISTANCE OF WOODS

No wood is immune to marine-borer attack. A few tropical woods appear to be very resistant and usually are attacked very slowly, but the results are greatly affected by local conditions. Records of long life are available from individual installations of several species, but it is usually possible to find other records showing much shorter life for the same species. No commercially important wood of the United States has sufficient marine-borer resistance to justify its use untreated in any important permanent structure where borers are active.

METHODS OF PROTECTION AGAINST MARINE BORERS

The best practical protection for piling in sea water is heavy treatment with coal-tar creosote or creosote-coal tar solution. The treatment must be thorough, the penetration as deep as possible, and the absorption high in order to give satisfactory results in heavily infested waters. It is best to treat such piling by the full-cell process "to refusal"; that is, to force in all the oil the piling can be made to hold without using treatments that cause serious damage to the wood. The absorptions recommended on page 273 are minimum values. When maximum protection against marine borers is desired as much more oil as is practicable should be injected. For highest absorptions it is necessary to air-season the piling before treatment.

Limnoria, *Martesia*, and *Sphaeroma* are not always stopped even by thorough creosote treatment. The average life of well-creosoted structures is many times the average life that could be obtained from untreated structures; nevertheless, well-creosoted structures are sometimes damaged seriously.

Shallow or erratic penetration affords but slight protection. The spots with poor protection are attacked, and from them the borers spread inward and destroy the untreated interior of the pile. Low absorption, also, fails to make the wood sufficiently poisonous to keep the borers out or to provide a reservoir of surplus oil to compensate for depletion by evaporation and leaching.

When wood is to be used in salt water, avoidance of cutting or injury after treatment is even more important than when it is for land use. No cutting or injury of any kind for any purpose should be permitted in the under-water part of the pile. Where piling is cut to grade above the water line the exposed surfaces should, of course, be protected from decay.

The San Francisco Bay marine piling committee estimated a range of 15 to 30 years for creosoted piling on the Pacific coast (Hill and Kofoid), the life obtained in individual cases depending in part on the severity of attack but mainly on the thoroughness of treatment and the care and intelligence used in avoiding damage to the creosoted shell in handling or installing the piling. On the North Atlantic coast longer life is to be expected, while in the South Atlantic and Gulf waters the range is lower.

If the importance of the structure and the difficulty or expense of renewing piling are great enough to justify additional expense for insurance against attack in heavily-infested waters, the treated piling may be surrounded by a jacket of concrete, or by clay, tile, concrete, or cast-iron pipe sections. The iron pipe would be the least liable to damage by breakage and also the most expensive. The pipe sections should extend from above high tide to a sufficient depth below the mud line to avoid the possibility of exposing the wood by scour, and the space between the wood and the pipe should be filled with concrete.

Paint and batten methods of pile protection (Hill and Kofoid) very as to details but consist substantially in, (1) coating the untreated pile with a thick, viscous paint which may or may not contain poisonous materials, (2) applying burlap, roofing felt, or similar material over the paint, (3) a second coat of paint, (4) a close-fitting layer of narrow battens nailed in place, and (5) a final coat of the paint to fill the crevices between the battens and coat the surface thoroughly. Experience has shown that only moderate extension of life is to be expected from such treatment. With care in treatment, handling, and driving it has been estimated that a life of 5 to 8 years may be expected from Douglas fir piling given such treatment in San Francisco Bay, but this may be greatly reduced by lack of care. In warmer waters the life would be less. There would also be the danger of earlier destruction by decay of the untreated upper parts of the piles.

Many attempts have been made to protect piling by sheathing it with sheet copper, Muntz metal, or other corrosion-resistant metal, but they have not generally been successful. Theft, damage in driving, damage by storm or driftwood, and corrosion have sooner or later let the borers in, and in only a few cases reported has long life been obtained. As long as a complete covering of metal can be maintained the borers cannot get in, but complete avoidance of damage to the coating has usually been found impractical.

Surface coatings of preservatives or paints can give very little increase in life in borer-infested waters. Damage from storms, the rubbing of boats, or other causes breaks through the coating in spots and allows the borers to work unhindered.

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WOOD PRESERVATION

The life of wood placed under conditions favorable to decay or attack by insects or marine borers can be considerably extended by treatment with suitable preservatives, and the cost per year of service greatly reduced below that of similar wood without treatment (MacLean, second reference).[39] Some preservatives are more effective than others. All possess certain disadvantages that limit their use, as well as advantages that make them especially suitable for specific purposes. These preservatives fall into three general classes: Those of an oily nature which are relatively insoluble in water; certain salts that are injected into wood in the form of water solutions; and those in which the toxic constituent is carried in some colorless, usually volatile solvent other than water.

COAL-TAR CREOSOTE

Coal-tar creosote is a black or brownish oil made by distilling coal tar. The first fractions collected in tar distillation are the light oils, the residue is pitch, and in between comes the portion that is saved for wood-preserving purposes. The character of the tar used, the method of distillation, the degree to which the distillation is carried, and the portion of the distillate that is included in the creosote fraction all govern the character of the creosote oil.

The character of the various coal-tar creosotes available, therefore, may vary to a considerable extent (Bateman). Small differences in character, however, do not prevent creosotes from giving good service, and satisfactory results in preventing decay may be expected from any reasonable good grade of coal-tar creosote.

Coal-tar creosote is the most important and most generally useful wood preservative. Its advantages are (1) its toxicity to wood-destroying fungi and insects, (2) its relative insolubility in water, and its low volatility, which impart to it a great degree of permanence under the most varied conditions, (3) its ease of application, (4) the ease with which its depth of penetration can be determined, and (5) its general availability and relatively low cost.

Although for general outdoor service in structural timbers there is as yet no better preservative than coal-tar creosote, for some special purposes it has certain properties that are a disadvantage. Without question, freshly creosoted timber can be ignited easily and will burn readily, producing a dense smoke. After the timber has seasoned some months, however, the more volatile parts of the oil disappear from near the surface and the creosoted wood usually is but little, if any, easier to ignite than untreated wood. On the other hand, after untreated wood has started to rot it is easier to

[39] For further information, the references at the end of this section should be consulted.

ignite than timber that has been kept sound by creosote treatment. The extent to which creosoted wood after being in service for a considerable period should be regarded as a fire hazard has never been satisfactorily determined. Opinions among engineers differ. Because of the uncertainty there appears to be some justification for a recommendation that in places where fire hazard is considered of utmost importance a preservative other than creosote should be used, unless the treated wood is protected in some way from fire.

The odor of creosoted wood is unpleasant to some persons and may be found objectionable in dwellings, but creosoted wood can probably be used in sills and foundation timbers, floor sleepers embedded in or resting on concrete, and even subflooring with little danger of the odor becoming objectionable. Foodstuffs that are easily affected by odors should not be stored near creosoted wood. Workmen sometimes object to the use of creosoted wood because it might soil their clothes and because it sometimes burns the skin of the face and hands, causing an effect similar to sunburn. There need be no fear, however, that creosoted timber has a serious effect on the health of workmen handling or working near it, or on the health of the occupants of buildings in which creosoted material has been used.

The color of creosote and the fact that it usually cannot be painted over satisfactorily make it unsuitable for finish lumber or other material where appearance and paint receptivity are of major importance.

CREOSOTE SPECIFICATIONS

A number of specifications prepared by different organizations are available for creosote oils of different kinds. Although the oil obtained by following most of them will probably be sufficiently effective in preventing decay, some of them are unnecessarily difficult to meet and others are unnecessarily loose. The following specification (American Wood Preservers' Association, fourth reference; U. S. Federal Specifications Board; and the American Railway Engineering Association) covering coal-tar creosote is in common use by the United States Government and by industrial concerns, and generally gives satisfactory results. Although the title of this specification refers only to ties and structural timbers, the oil is equally suitable for other kinds of timber. Substantially all creosote producers can meet this specification without difficulty.

AMERICAN WOOD PRESERVERS' ASSOCIATION STANDARD SPECIFICATION FOR CREOSOTE OIL FOR TIES AND STRUCTURAL TIMBERS

1. The oil shall be a distillate of coal-gas tar or coke-oven tar.[40] It shall comply with the following requirements:

2. It shall not contain more than 3 percent of water.

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[40] Owing to the complexity of the chemical composition and physical properties of coal-tar creosote oil, and to the fact that some of the same compounds and properties which characterize coal-tar creosote are found in certain petroleum derivatives, the determination of the purity of creosote oil is difficult. When there is not certain assurance that the oil is a pure product, the following tests will aid in arriving at an opinion as to its coal-tar origin: (1) The fraction distilling between 210° and 235° C. is usually solid or contains some solids when cooled to 25°; (2) All of the fractions up to 315° contain tar acids in varying amounts, usually at least 1 percent calculated on the amount of the fraction tested; (3) the specific gravity of the fraction between 235° and 315° is usually not lower than 1.025, and the specific gravity of the fraction between 315° and 355° is usually not lower than 1.085 at 38° compared with water at 15.5°. However, some pure coal-tar distillates fall slightly below these limits. If the oil does not comply with at least one of the foregoing tests, it is undoubtedly not a pure coal-tar creosote.

3. It shall not contain more than 0.5 percent of matter insoluble in benzol.[41]
4. The specific gravity of the oil at 38° C. compared with water at 15.5° shall not be less than 1.03.
5. The distillate, based on water-free oil, shall be within the following limits:

Up to 210° C., not more than 5 percent.
Up to 235° C., not more than 25 percent.

6. The residue above 355° C., if it exceeds 5 percent, shall have a float test of not more than 50 seconds at 70°.
7. The oil shall yield not more than 2 percent of coke residue.
8. The foregoing tests shall be made in accordance with the standard methods of the American Wood Preservers' Association.

This specification does not limit the amount of residue above 355° C. Some purchasers add a special requirement limiting the amount to some definite maximum, such as 25 percent.

WATER-GAS-TAR CREOSOTE

Water-gas-tar creosote is made from water-gas tar in much the same way that coal-tar creosote is made from coal tar. Water-gas tar is the tarry residue remaining from the use of petroleum oils in the manufacture of water gas. It is therefore a petroleum product and not a coal product, and the composition of both the water-gas tar and its creosote are different from the respective coal products (Bateman). Water-gas-tar creosote is not considered so toxic or so generally effective as coal-tar creosote, but it has good preservative value. Aside from lower toxicity, the advantages and disadvantages of water-gas-tar creosote are generally similar to those of the coal-tar product. Water-gas tar and water-gas-tar creosote are used to some extent with coal-tar creosote mixtures in the treatment of railway ties.

WOOD-TAR CREOSOTE

Wood-tar creosotes are made by distilling wood tar. Just how they compare in effectiveness with coal-tar creosote has not been established, but it is certain that when of good quality they are very effective. Wood-tar creosotes are not extensively used for preserving wood because they have never been produced in sufficiently large quantities of satisfactory and uniform quality and price to attract the attention of large consumers.

TAR

Tars that are highly viscous cannot be used alone to advantage for preserving wood, because they do not penetrate wood well. Surface coatings of tar have been found to be of little value. Certain tars, however, when made to penetrate deeply have given good results in service tests.

It is a common practice to mix coal tar or water-gas tar with coal-tar creosote, the proportion of tar being sometimes as high as 50 percent. If clean tars are used that do not interfere too seriously with penetration such solutions are very effective. Tar solutions are

[41] Samples of oil taken from working tanks may show an increase in matter insoluble in benzol due to treating operations. Such increases, provided they do not exceed by 1 percent the specification limits, should not serve to cause rejection of the oil for nonconformity with specifications if it can be shown that the original fresh oil was of specified quality.

cheaper than straight creosote and should give better protection against checking of the wood in service. They leave the wood less clean than creosote and penetrate less easily.

PETROLEUM OILS

Crude petroleum, "topped" petroleum, fuel oil, and waste crankcase oil are frequently suggested as possible wood preservatives and many experiments have been made with them. Experience has demonstrated, however, that chemically unchanged petroleum oils used alone are not to be relied upon. Occasionally good results have apparently been obtained, but in other instances complete failure has resulted.

Petroleum is extensively used as a diluent for creosote in the treatment of railway ties, most commonly in the proportion of about 50 percent of each. The mixture is less toxic than straight creosote, but if suitable creosote and petroleum are used, and sufficient of the mixture is injected, entirely satisfactory protection from decay is to be expected. The advantages and disadvantages of the mixture in comparison with straight creosote are as stated for tar solutions, except that tar solutions should generally have higher toxicities than petroleum mixtures.

ZINC CHLORIDE

Zinc chloride is the water-soluble wood preservative most extensively used in the United States. The principal advantages of this salt are relative cheapness, general availability, uniformity of quality, cleanliness, ability of the treated wood to take and hold paint, lack of odor, ease of shipment, and lack of fire hazard. Its chief disadvantage is its solubility in water, which permits it in time to be leached out of wood when in contact with wet soil or periodic wetting. The water that is injected with it temporarily adds considerably to the weight of the wood and in order to avoid shrinkage troubles must be dried out before the wood is used under dry conditions where shrinkage would be objectionable.

When injected into wood in the usual quantity (about one-half to 1 pound of dry salt per cubic foot) zinc chloride has a slight effect in reducing inflammability.

Zinc chloride treated wood is finding increasing use in the construction of buildings, especially in the roof planking of factory buildings where high relative humidity favors the rapid decay of the roofs. The facts that the net weight of the wood (after seasoning) is not greatly increased by the treatment and that the treated wood is clean and paintable and to a slight extent fire resistant favor its use in such places.

The following zinc chloride specifications of the American Wood Preservers' Association (fourth reference) is the one generally used in the purchase of zinc chloride for wood preserving purposes:

> The zinc chloride shall be acid free and shall not contain more than 0.1 percent iron. Fused or solid zinc chloride shall contain at least 94 percent chloride of zinc. Concentrated zinc chloride solution shall contain at least 50 percent chloride of zinc.

The concentrated zinc chloride is diluted with water to solutions of about 3 to 5 percent strength for use in treating wood.

SODIUM FLUORIDE

Sodium fluoride (in mixture with other materials) has been used to some extent in Europe for preserving wood, especially mine timbers. In the United States it has been used alone experimentally in railway ties and in mine ties and timbers since 1914 and has also been used to some extent commercially in the treatment of factory roof timbers. The evidence thus far available indicates that it is a good wood preservative. For the most part its advantages and disadvantages are similar to those of zinc chloride. The chief disadvantages is its relatively high price, which in recent years has been roughly one and one-half times that of zinc chloride. It can also be precipitated by salts of calcium and thus in time be made ineffective in soils having a high lime content. Sodium fluoride is an important ingredient in several proprietary or patented preservatives.

ARSENIC

Arsenic in various forms, either alone or mixed with other substances, has been used as a wood preservative for a number of years, and a considerable quantity of poles, ties, and other material treated with it is now in service. It is still too early to tell how effective the various forms and combinations of arsenic will be, but some of them have given promising results thus far. Arsenic salts are toxic to many fungi but there are some fungi that, under conditions favorable to their growth, can live in the presence of arsenic salts and even convert them slowly into poisonous gas. Certain investigators believe that the small amounts of arsenical gases that may be produced in this way in a building are dangerous to the health of the occupants. Others do not share this belief. The question is still unsettled but should be given consideration in connection with the use of arsenical preservatives in any place where there is insufficient ventilation to carry away the gases as rapidly as they may be produced.

COPPER SULPHATE

Copper sulphate, which has been used in Europe as a wood preservative for many years, is known to be effective in retarding decay. It is no more effective than zinc chloride or sodium fluoride, however, and has no especial advantages over them. The chief disadvantage of this preservative is the fact that it attacks iron and steel and therefore cannot be used in ordinary treating equipment. It has never been used extensively in the United States for preserving wood.

MERCURIC CHLORIDE

Mercuric chloride (corrosive sublimate) is effective in prolonging the life of wood, but its relatively high price, its extremely poisonous character, and its corrosiveness to metal have militated against it. Although it is still used to some extent in Europe, either alone or mixed with sodium fluoride, and has been used to a slight extent for many years in the United States, it will probably never be extensively used in this country.

PROPRIETARY PRESERVATIVES

Many preservatives are sold under trade names of various kinds. Some of them are ordinary coal-tar creosote or coal-tar creosote that has been modified slightly by taking out some of the solid ingredients. Others have had the lighter fractions removed, making them higher boiling than the ordinary run of creosote. In the main, preservatives thus derived from coal-tar creosote are good preservatives and may be used with assurance. Whether it is economical to use them depends upon their convenience and their cost as compared with coal-tar creosote or zinc chloride.

Other proprietary preservatives contain wood-tar products or other oils. Their value is not so well established, but no doubt some of them have value.

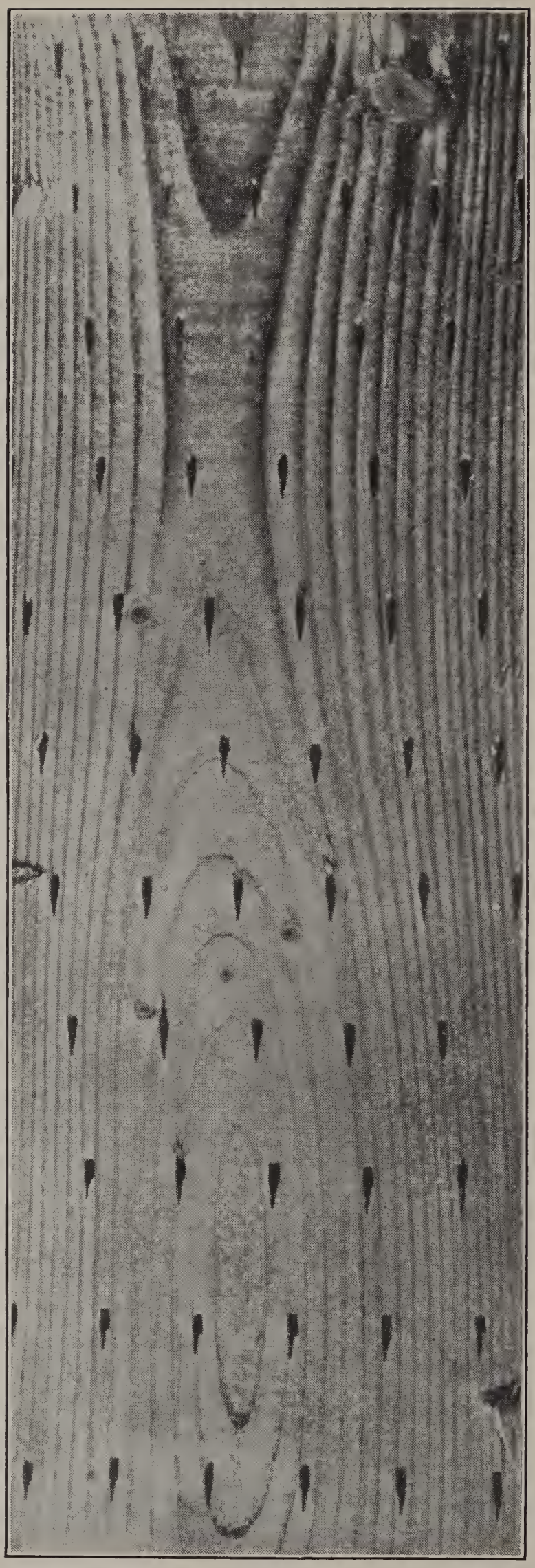
In a third group are preservatives injected in water solutions. Whether or not these are good depends on the materials of which they are composed, but several appear to be giving promising results. Before buying a preservative of this kind the purchaser should insist upon knowing its ingredients and their proportions; investing money in secret preservatives is unnecessary and unwise.

A fourth group of proprietary preservatives is being developed in which the toxic chemical is carried into the wood in a colorless solvent other than water. Preservatives of this kind find use particularly in the treatment of flooring, furniture, and millwork exposed to fungous and termite attack, window sash and frames, and automobile woodwork, where clean treatment without swelling is required. Evidence on the degree of effectiveness of these preservatives is very incomplete and several of them are of very recent origin, but as a group they promise to be useful. The user of such preservatives should insist upon knowing the nature and amount of the effective chemicals in the mixture.

The literature advertising some of the proprietary preservatives frequently contains extravagant claims as to their properties and their effectiveness. Obviously such claims should be greatly discounted. There are very few, if any, proprietary preservatives for general use, regardless of price, that have yet shown themselves to be better or more generally satisfactory than straight coal-tar creosote and zinc chloride in their respective classes, although some of the proprietary preservatives have advantages for special uses.

PREPARING TIMBER FOR TREATMENT

For satisfactory results with any treating process the timber must be sound and suitably prepared for treatment. Preservatives will not make weak timber strong or restore the strength of timber that has been partially destroyed by decay. Further, except in material of small dimensions the preservative and the heat of the treating process cannot be expected always to kill all the fungous growth in an infected or partially decayed stick. Hence any fungus present may continue to grow after treatment, perhaps destroying completely the unpenetrated interior of the timber.



Incisions made in timber prior to treating with preservatives.

PEELING

Peeling round or slabbed timber is necessary to enable it to season quickly enough to avoid decay and insect damage and also to permit the entrance of preservatives, as they will not penetrate bark satisfactorily.[42] Strips of even the thin inner bark may prevent penetration. Patches of bark left on during treatment usually fall off in time and expose untreated wood, thus permitting decay to reach the interior of the timber. Careful peeling is especially important for wood that is to receive an inexpensive surface treatment. In the more thorough processes some penetration will take place both lengthwise and tangentially in the wood, and consequently small strips of bark are not quite so harmful.

SEASONING

Applying surface treatments of preservative oils to green or wet wood is practically useless, because preservatives so applied cannot penetrate wood that is already full of water. Plants treating timber by pressure processes, however, can use artificial means of conditioning green timber to make it more absorptive and thus avoid the long delay incident to air seasoning. Nevertheless, air seasoning, despite the greater time, labor, and storage space required, is the most widely used method of conditioning and is in general, although not always, the cheapest and most effective even for pressure treatment.

The amount of air seasoning required will depend on climate, the location and condition of the seasoning yard, the methods of piling, the season of the year, and the size, species, and character of the timbers (Mathewson). It is not uncommon in commercial practice to season railway ties and larger timbers for 8 to 12 months if conditions permit and if the timber can be kept that long under local conditions without deterioration, but the desirability of so long a drying period is not fully established. A great deal can be accomplished even with large pieces in 3 to 6 months of good seasoning weather. Small pieces season more quickly than large pieces and sapwood more quickly than heartwood. The most satisfactory seasoning practice for any specific case will depend on the individual drying conditions and the preservative treatment to be used and must be determined by experience.

It is not necessary that the timber be seasoned to a uniform moisture content throughout, but the part that is to be penetrated by the preservative must have enough water removed to make room for the preservative to enter. The exact moisture content at which air-seasoned wood takes treatment best has not been determined.

INCISING

Wood that is resistant to penetration by preservatives is sometimes incised (pl. 6) before treatment to permit deeper and more uniform penetration. To accomplish this, sawed or hewed material is passed through a machine having horizontal and vertical rollers equipped with teeth that sink into the wood to a predetermined depth, usually one-half to three-fourths of an inch. The teeth are spaced so as to give the desired distribution of preservative with the minimum num-

[42] The Boucherie and similar processes in which a preservative is forced through green wood lengthwise do not require peeling of the timber, but they are little used in the United States.

ber of incisions. A machine of different design is required for incising the butts of poles. The effectiveness of incising depends on the fact that preservatives usually penetrate into wood much farther in a longitudinal direction than in a direction perpendicular to the faces of the stick. The incisions expose end-grain surfaces and thus permit longitudinal penetration. Incising is practiced chiefly on Douglas fir ties and timber and cedar poles but is employed to some extent on ties of various other species. It is especially effective in improving penetration in the heartwood areas of sawed or hewed surfaces.

CUTTING AND FRAMING

All cutting, framing, and boring of holes should be done before treatment (American Wood Preservers' Association, fourth reference). Cutting into the wood in any way after treatment will usually expose the untreated interior of the timber and permit ready access to decay fungi. Railroads and other large users are now to a large extent following the practice of framing before treatment (Stimson) and find it not only practical but also economical.

PRESSURE PROCESSES

The most effective method of treating wood with preservatives is by pressure processes, all of which use the same general principle (American Wood Preservers' Association, first reference; MacLean, last reference; and Weiss). The timber to be treated is placed on steel cars and run into a long steel cylinder, which is then closed and filled with preservative. Pressure is applied to force the preservative into the wood until the desired amount has been absorbed. Two principal types of pressure treatment, the full-cell and the empty-cell, are in common use.

FULL-CELL PROCESS

The full-cell or Bethell process is widely used with preservatives in water solution or with oils when the retention of a maximum volume of preservative is desired, but it is not so satisfactory with oils when limited absorptions are specified. Limited absorptions of preservatives in water are usually obtained by regulating the strength of solution rather than by limiting the volume of preservative injected, hence full-cell treatment is very suitable for these preservatives. The steps in this process, when using seasoned timber, are essentially as follows:

(1) After the charge of timber has been placed in the treating cylinder a preliminary vacuum is applied to remove the air from the cylinder and as much as possible from the wood.

(2) The preservative, previously heated to somewhat above the desired treating temperature, is admitted to the cylinder without the admission of air.

(3) After the cylinder has been filled, pressure is applied until the required absorption of oil is obtained.

(4) When the pressure period has been completed the preservative is withdrawn from the cylinder.

(5) A short final vacuum is usually applied immediately afterward to free the charge from dripping preservative.

When the timber is steamed before treatment the preservative is admitted at the end of the vacuum period that follows steaming. When the material has received preliminary treatment by the Boulton, or boiling-under-vacuum process, the cylinder can be filled and pressure applied as soon as the conditioning period has been completed.

EMPTY-CELL PROCESSES

The object of empty-cell treatment is to obtain deep penetration with a relatively low net retention of preservative. Empty-cell treatments should be used with preservative oils in preference to full-cell treatment except when maximum absorptions are desired but are not important for injecting water solutions except when it is desired to keep the water absorption as low as possible by using solutions of greater strength than are commonly used. Two empty-cell treatments are commonly employed, both of which make use of the expansive force of compressed air to drive out part of the preservative absorbed during the pressure period.

RUEPING PROCESS

The Rueping empty-cell process (often referred to as the empty-cell process with initial air) has been widely used for many years, both in Europe and in the United States. The following general procedure is observed, after the timber has been seasoned or conditioned:

(1) Air under pressure is forced into the treating cylinder, which contains the charge of timber. The air penetrates some species easily, requiring but a few minutes application of pressure. In the treatment of the more resistant species common practice is to maintain air pressure from one-half to a full hour before admitting the preservative. The air pressures employed generally range between 25 and 100 pounds per square inch, depending on the net retention of preservative desired and the resistance of the wood.

(2) After the application of preliminary air pressure, the preservative is admitted to the cylinder. During the filling process the air in the treating cylinder interchanges with the preservative at the same pressure in an equalizing or Rueping tank, or it is gradually allowed to escape from the treating cylinder as the preservative enters at a rate that keeps the pressure within the cylinder constant. When the treating cylinder has become filled with preservative the treating pressure is raised to a higher point and continued until the point of refusal is reached or until the gross absorption is sufficient for the required net retention of preservative.

(3) At the end of the pressure period the preservative is drained from the cylinder, and a final vacuum removes the surplus preservative from the wood.

LOWRY PROCESS

The Lowry process is often called the empty-cell process without initial air. The chief difference between the Lowry and the Rueping process is that the Rueping employs initial air pressures above atmospheric. In the Lowry process the preservative is admitted to the cylinder without either an initial air pressure or a vacuum. The air

originally in the wood is imprisoned during the filling period. After the cylinder has become filled with the preservative, pressure is applied; the remainder of the treatment is the same as described for the Rueping treatment.

The Lowry process has the advantage that the equipment for the full-cell process can be used without other accessories, whereas the Rueping process usually requires additional equipment, such as an air compressor, and an extra cylinder or Rueping tank for the preservative, or a suitable pump to force the preservative into the cylinder against the air pressure. Both processes, however, have advantages and both are widely and successfully used.

CONDITIONING GREEN TIMBER FOR PRESSURE TREATMENT

When air seasoning is impractical because of lack of time, poor seasoning conditions, or danger of decay during the seasoning period, or when for any reason it is preferred to treat timber in the green condition, either of two commonly used methods for conditioning may be selected. One is the steaming-and-vacuum process, which is employed mainly for southern yellow pine, and the other is the Boulton, or boiling-under-vacuum process, which is used for Douglas fir and to some extent for hardwoods. In the steaming process (American Wood Preservers' Association, second reference) the green material is steamed in the treating cylinder for several hours, commonly at 20 pounds gage pressure (259° F.), and when the steaming has been completed a vacuum is immediately applied. During the steaming period the outer part of the wood is heated to a temperature approaching that of the steam (MacLean, fifth reference), and the subsequent vacuum lowers the boiling point so much that part of the water is evaporated from the wood. The steaming and vacuum periods employed depend on the size, species, moisture content of the material, and the judgment of the plant operator. The steaming method usually reduces the moisture content of green wood somewhat and assists greatly in getting the preservative to penetrate, but it does not reduce the moisture content to a point where the wood can properly be called seasoned.

In the Boulton, or boiling-under-vacuum, method (American Wood Preservers' Association, third reference; MacLean, last two references) of partial seasoning, the timber is heated in the preservative oil under vacuum at temperatures usually about 180° to 210° F. This temperature range, lower than that of the steaming process, is a considerable advantage in treating woods that are especially susceptible to injury from high temperatures. The Boulton method removes more water from green wood than does the steaming-and-vacuum method and materially reduces the moisture content of the outer inch or two but makes little change in the moisture content inside of this outer zone in heartwood timbers.

TREATING PRESSURES AND PRESERVATIVE TEMPERATURES

The pressures used in the full-cell and Lowry treatments vary from about 100 to 200 pounds per square inch, depending on the ease with which the wood takes the treatment, but are most commonly about 150 to 175 pounds per square inch. Pressures applied in the Ruep-

ing treatment are usually between 150 and 200 pounds per square inch, depending on the preliminary air pressure employed.

Specifications commonly require that the temperature of the preservative during the pressure period shall be not less than 160° nor more than 200° F. and shall average at least 180°. Since high temperatures are much more effective than low temperatures in treating resistant wood, better penetration would be obtained by using temperatures between 190° and 200° (MacLean, first and third references); this applies to both preservative oils and water solutions.

ABSORPTION AND PENETRATION

The amount of oil usually injected into structural timber for land use, in the full-cell process, varies generally from 10 to 16 pounds per cubic foot. Piling to be used in salt water in which marine borers are active should be treated practically to refusal, which may mean 20 pounds per cubic foot or even more for southern yellow pine having thick sapwood, and 14 to 16 pounds per cubic foot for Douglas fir. In the empty-cell processes absorptions of 6 to 12 pounds per cubic foot are commonly used in ties, lumber, and timbers, depending upon the species, the proportion of sapwood, and the conditions under which the timber is to be used. The absorptions in material that is largely heartwood and of small cross section should be greater than the absorptions in larger sizes in order to obtain equivalent protection (MacLean, fourth reference), because of the greater proportion of surface area to volume in the smaller sizes. More than twice as much absorption per cubic foot may be required in very small sizes to obtain a penetration as good as that in large timbers. For unusually large heartwood timbers the absorption per cubic foot may have to be reduced. Sapwood timbers or species, like red oak, that have easily treated heartwood should have higher absorptions than timbers that consist largely of resistant heartwood.

The minimum absorptions of creosote and of zinc chloride required in timber of various kinds for use by the Federal Government (U. S. Federal Specifications Board) are shown in table 50. Higher absorptions are usually required for best results, especially in material that is largely sapwood.

Penetrations vary widely even in pressure-treated material. In most species heartwood is more difficult to penetrate than sapwood, and there are also great differences between species in the degree to which heartwood may be penetrated; the heartwood of white oak, red gum, and mountain-region Douglas fir, for example, is practically impenetrable by commercial treating processes. Penetrations in unincised heart faces of these species may sometimes be as deep as one-fourth inch, but usually are less and often are not more than one-sixteenth inch. Long experience has shown that even these slight penetrations have value, although deeper penetrations are highly desirable. The heartwood of coast-region Douglas fir, southern yellow pine, and various hardwoods, while quite resistant, can be made to take penetrations from one-fourth to one-half inch on the average and sometimes considerably more. Incising is beneficial for most of these species. The heartwood of black gum, ponderosa pine, most of the red oaks, and the light-colored heartwood in beech, can

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be penetrated deeply. It should be the ideal in all pressure treatments to have the sapwood penetrated completely. This can always be accomplished in small-sized pieces and, with skillful treatment, to a considerable extent in piling, poles, ties, and structural timbers. It is not practical, however, for the operator to insure complete penetration of sapwood in every piece when treating large pieces of round material having thick sapwood, such as southern pine poles and piling. The lower the absorption the greater the difficulty of obtaining complete penetration of sapwood. Better penetrations are obtained for a given absorption by empty-cell treatment than by full-cell treatment, especially when medium to low absorptions are used.

SPECIFICATIONS

Specifications covering the details of treatment by various pressure processes and by the hot-and-cold-bath process for poles have been prepared by the American Wood Preservers' Association (fourth reference). These specifications are in use by the Federal Government and by some States (table 50). They have proved fairly satisfactory, but are capable of improvement. The specifications allow some latitude to the purchaser in meeting individual requirements. The specifications of the American Railway Engineering Association, pages 1273–1318, covering treatment are in general similar to those of the American Wood Preservers' Association.

HANDLING TIMBER AFTER TREATMENT

Treated timber should be handled with sufficient care to avoid breaking through the treated portion. The use of pikes, cant hooks, picks, tongs, or other pointed tools that dig deeply into the wood should be prohibited. Spikes or dogs may be driven into piling near the point and near the butt when needed for forming log booms, but they should never be driven into the part of the pile that will be exposed in service. Handling heavy loads of lumber or sawed timber in rope or cable slings may crush the corners of the outside pieces. Breakage or deep abrasions may also result from throwing the material or dropping it any considerable distance. When damage has resulted through carelessness or otherwise, the exposed places should be retreated as thoroughly as conditions permit.

FIELD TREATMENT OF CUT SURFACES

Although cutting into wood after treatment is highly undesirable, it cannot always be avoided. When cutting is necessary the damage may be partly overcome in timber for land or fresh-water use by thoroughly brushing the cut surfaces with coal-tar creosote. Two coats of hot oil should be given if practicable, but a cold application is better than none. Brush coating cut surfaces, however, gives little protection against marine borers. For wood treated with water-soluble preservatives, where the use of creosote is not practicable, a strong solution of the preservative in use may be substituted. In treating the surface exposed when pile heads are cut off, the brush treatment should be given with great care and thoroughness. A coat of pitch, asphalt, or similar material may well be then applied

TABLE 50.—*Federal specifications for preservative treatment of wood*

(Schedule of recommended practice in the preservative treatment of timber in various forms)[1]

Form of product and service	Preservative: Kind	Preservative: Specification no.: Federal [2]	Preservative: Specification no.: American Wood Preservers' Association [3]	Minimum absorption per cubic foot [4]: Empty-cell treatment	Minimum absorption per cubic foot [4]: Full-cell treatment	American Wood Preservers' Association specification no. for treatment	Remarks
				Pounds	*Pounds*		
Crossties (all species except Douglas fir).	Coal-tar creosote or creosote coal-tar solution.	TT-W-556 or TT-W-566.	4d or 5b	6	12	34b	Empty-cell treatment is recommended for all ordinary conditions of use; full-cell treatment only for exceptional conditions.
Crossties (Douglas fir incised)	do	do	do	6	12	38a	
Crossties (all species except Douglas fir).	Zinc chloride	TT-W-576	17a		(5)	34b	Not recommended for arid or very wet regions.
Crossties (Douglas fir)	do	do	do		(5)	38a	
Piling (except Douglas fir), for land or fresh water use).	Coal-tar creosote or creosote coal-tar solution.	TT-W-556 or TT-W-566.	4d or 5b	8	16	39a	Full-cell treatment is recommended for important permanent structures where long life is of special importance or for use in warm humid regions, but 12-pound empty-cell treatment may be substituted for it.
Piling (except Douglas fir), for marine use).	Coal-tar creosote	TT-W-556	4d		16	39a	For North Atlantic waters where marine-borer attack is not especially severe.
Piling (except Douglas fir) for marine use under severe service conditions.	do	do	do		22	39a	For waters where marine-borer attack is usually severe.
Piling (Douglas fir) for land or fresh water use.	Coal-tar creosote or creosote coal-tar solution.	TT-W-556 or TT-W-566.	4d or 5b	8	12	41a	Full-cell treatment is recommended for important permanent structures where long life is of special importance or for use in warm, humid regions.
Piling (Douglas fir) for marine use	Coal-tar creosote	TT-W-556	4d		14	41a	For use in all waters where marine borers are active.
Poles (pine), under ordinary service conditions.	do	do	do	8		36b	For use in the United States.

[1] The specifications do not provide for brush, spray, or open-tank treated lumber and timber, and such treatments are not recommended when it is possible to use pressure-treated material. When pressure treatment is out of the question, however, and brush, spray, and open-tank treatments are the only treatments practicable they may be used. Hot-and-cold-bath open-tank treatment is the best of the nonpressure treatments. Federal Specification TT-W-556 for creosote oil for pressure treatment may be employed. The liquid creosotes or anthracene oils covered by Federal Specification TT-W-561 are more convenient to handle, but are not necessarily more effective than the oils covered by Federal Specification TT-W-556. Brush and spray treatments are only surface treatments and can not be expected to have any great degree of permanence, nor can they be expected to have any effect if used after the wood is already infested with decay or insects.

[2] These specifications are the same as the corresponding ones of the American Wood Preservers' Association.

[3] The letters in this column are those of the specification in use in 1933. The latest revision of the respective American Wood Preservers' Association specification should be used.

[4] The absorption indicated are minimum absorptions, which can be increased to meet special service conditions. especially with crossties and piling.

[5] ½-pound dry salt per cubic foot.

TABLE 50.—*Federal specifications for preservative treatment of wood*—Continued

Form of product and service	Preservative: Kind	Preservative: Specification no.: Federal	Preservative: Specification no.: American Wood Preservers' Association	Minimum absorption per cubic foot: Empty-cell treatment	Minimum absorption per cubic foot: Full-cell treatment	American Wood Preservers' Association specification no. for treatment	Remarks
				Pounds	*Pounds*		
Poles (pine), under severe service conditions.	Coal-tar creosote	TT-W-556	4d	12	16	36b	For use in tropical regions.
Poles (Douglas fir), under ordinary service conditions.	do	do	do	8		41a	For use in the United States.
Poles (Douglas fir), under severe service conditions.	do	do	do		12	41a	For use in tropical regions.
Poles (cedar, incised) butt treatment	do	do	do			43b	
Poles (chestnut, not incised) butt treatment.	do	do	do			44b	
Fence posts	Coal-tar creosote or creosote coal-tar solution.	TT-W-556 or TT-W-566.	4d or 5b	6		37b	Round posts are recommended.
Structural timber (pine), less than 5 inches in thickness.	do	do	do	10	16	35c	Full-cell treatment is recommended for all timber to be used under salt water. Empty-cell treatment is suitable for most ordinary purposes.
Structural timber (pine), greater than 5 inches in thickness.	do	do	do	8	12	35c	
Building lumber and dimension (except Douglas fir), to be painted.	Zinc chloride	TT-W-576	17a		(6)	35c	Recommended for building lumber not in contact with the ground for use where painting is desirable or creosoted material is otherwise unsuitable.
Building lumber and dimension (Douglas fir), to be painted.	do	do	do		(6)	38a	
Structural timber (Douglas fir), less than 5 inches in thickness.	Coal-tar creosote or creosote coal-tar solution.	TT-W-556 or TT-W-566.	4d or 5b	10	16	45a	Full-cell treatment is recommended for all timber to be used under salt water. Empty cell treatment is suitable for most ordinary purposes.
Structural timber (Douglas fir), 5 to 9 inches in thickness.	do	do	do	8	10	45a	
Structural timber (Douglas fir), 10 to 14 inches in thickness.	do	do	do	6	8	45a	

[6] 1 pound dry salt per cubic foot.

over the creosote, followed by some protective sheet material such as metal, roofing felt, or saturated fabric fitted over the pile head and brought down the sides far enough to protect against damage to the top treatment and the entrance of storm water (American Wood Preservers' Association, fourth reference).

A small hand pump for forcing creosote into bolt holes bored after treatment is now on the market.

INSPECTION

GRADE AND QUALITY

Inspection of the timber for quality before treatment is desirable. When inspection previous to treatment is impractical, the purchaser can inspect for quality after treatment; if this is to be done, however, it should be made clear in the purchase order.

ABSORPTION

It is impractical to determine after treatment, by analysis or inspection of the treated wood, whether the specified absorption has been injected. This is because the nonuniform distribution of preservative throughout the length of the pieces affords no way to obtain a correct average sample from a charge of treated timber without destroying most of it. The purchaser must either accept the statements or affidavit of the treating-plant operator or have an inspector at the treating plant to observe the treatments and insure compliance with the specifications. Intelligent inspection at the treating plant is welcomed by plant operators. Railroad companies and other corporations that purchase large quantities of treated timber usually maintain their own inspection services. Commercial inspection and consulting service is available for those purchasers who are able to pay an inspection fee but who do not use enough treated timber to justify inspectors of their own.

PENETRATION

Penetration measurements should be made at the treating plant if inspection service is provided but can be made by the purchaser at any time after the timber has been treated. They give about the only measure of the thoroughness of treatment when professional inspection service is not available. Rejection of treated timber for insufficient penetration may be difficult to enforce, however, unless this point is definitely covered in the specifications or there is previous agreement with the plant operator on minimum and average penetration requirements.

The depth of penetration of creosote and other dark-colored preservatives can be determined directly by observing a boring removed by an increment borer. The boring should be taken at a distance of several feet from the ends of the piece in order to avoid the unrepresentative end portion that is completely treated by end penetration. In poles and posts the boring should be made at the point where the ground line will be when the pole or post is in service. Since the preservative oil has a tendency to creep over cut surfaces the boring should be split in half lengthwise and the observation should be made promptly. Holes made for penetration meas-

urements should be tightly plugged with a thoroughly treated wooden plug. Since penetration may be irregular a single boring is not necessarily a correct indication of average penetration in the timber bored or in the other timbers in the charge.

The penetration of preservatives that are practically colorless must be determined by chemical dips or sprays that show the penetration by color reactions. The penetration of zinc chloride is determined as follows (American Wood Preservers' Association, fourth reference): Prepare separately a 1-percent solution of potassium ferricyanide, a 1-percent solution of potassium iodide, and a 5-percent solution of soluble starch. In making the starch solution, boil until the starch is thoroughly dissolved, otherwise the reaction will be unsatisfactory. The starch solution should not be allowed to sour before use. The wood to be tested should be reasonably dry. Mix 10 cubic centimeters each of the three solutions and with a good atomizer, spray the mixture evenly on a freshly cut cross section of the wood. The treated portion will at once turn dark blue whereas the untreated portion will retain its original color. The color will fade with time unless renewed.

Other chemical mixtures have been developed by the promoters of proprietary preservatives for disclosing the penetration of their respective preservatives.

EFFECT OF TREATMENT ON STRENGTH

Coal-tar creosote, water-gas tar, wood-tar creosote, creosote-tar mixtures, and creosote-petroleum mixtures are practically inert to wood and have no chemical influence upon it that would affect its strength. The 2- to 5-percent solutions of zinc chloride commonly used in preservative treatment apparently have no important effect. Timber treated with any of these preservatives under moderate treating conditions and used under conditions that favor decay can properly be given working stresses as high as those for an untreated naturally durable wood under the same conditions of use.

Although wood preservatives are not harmful in themselves, the treatment necessary in injecting them into the wood, if not properly carried out, may result in considerable loss of strength to the wood and usually a considerably less loss in stiffness. Green wood conditioned for the injection of preservatives by steaming or by boiling under vacuum may be seriously reduced in strength if extreme temperatures or heating periods are employed (Hatt and Wilson). Consequently, care should be used to keep the temperature as low and the duration of the conditioning treatment as short as is consistent with satisfactory absorption and penetration of the preservative. A gage pressure of 20 pounds (or approximately 259° F.) is sufficiently high for steam conditioning. No advantage is known to result from higher pressures, and the resulting higher temperatures are much more likely to damage the wood. The maximum temperature employed in the boiling under the vacuum process is usually less than 210° F. The effect of temperature on strength is influenced by such factors as species of wood and size and moisture condition of the timbers treated. The loss in strength increases with moisture content and with size of timber.

The use of pressures greater than 175 pounds in injecting preservatives into wood that is soft from long heating is likely to cause severe end checking and collapse. Considerably higher pressures can be used if the wood has been heated for a short time only, or not at all. Woods of low density are more subject to injury from high pressures than woods of high density.

NONPRESSURE PROCESSES

In general, the application of preservatives by nonpressure methods is not so effective as pressure treatment. Nonpressure treatments should be employed only when it is impractical to use pressure-treated material.

HOT-AND-COLD-BATH PROCESS

The hot-and-cold-bath treatment (Hunt) is the most effective of the nonpressure processes, and the thoroughness of the treatment obtainable most nearly approaches that of the pressure processes. The treatment consists in heating the wood in the preservative in an open tank for several hours and then cooling it in the preservative for several hours. This may be accomplished (1) by transferring the wood at the proper time from a tank of hot oil to a tank of cold oil, (2) by draining the hot preservative from a single tank and quickly filling it with cold, or (3) more slowly, by shutting off the heat at the proper time and allowing the wood and the hot preservative to cool together.

The principle involved is that during the hot bath the heating causes the air and moisture in the wood to expand and some to be forced out. When the cooling takes place the air and the water vapor in the wood contract and a partial vacuum is thus created, drawing some of the preservative into the wood. Little absorption of preservative takes place during the hot bath, except in a few woods that are exceptionally easy to treat.

The chief use of the hot-and-cold-bath process has been in treating the butts of fence posts and of poles for telegraph, telephone, and power lines. The process is also useful for lumber or timbers for other purposes when circumstances do not permit the more effective pressure treatments. Coal-tar creosote is the preservative ordinarily chosen because it is generally the most suitable preservative for posts and poles; but water solutions, such as zinc chloride solution and the like, may also be employed if the necessary care is taken to keep the solution at uniform strength.

With coal-tar creosote, hot-bath temperatures up to 230° F. may be employed, as is done in the commercial butt treatment of cedar poles. Higher temperatures may give better penetrations; but if the temperature is too high, a considerable percentage of the oil may be lost by evaporation, especially if a creosote with a relatively low boiling range is used. In the cold bath a temperature of approximately 100° is usually about right. This temperature keeps the oil fluid but much cooler than the hot bath. If the oil is not sufficiently fluid at 100°, however, the temperature of the cold bath should be increased.

The length of both baths must be governed by the ease with which the timber takes treatment and the demand for speed. With

well-seasoned timber that is moderately easy to treat, a hot bath of 2 or 3 hours and a cold bath of like duration will probably be sufficient, but much will depend on the size, large sizes requiring longer heating than small sizes. In using coal-tar creosote the object is to obtain as deep a penetration as possible but with a minimum amount of oil. If the penetration is not sufficient, either the hot or the cold bath should be lengthened. If the penetration is satisfactory, but too much oil is absorbed or the material drips too much after treatment, the cold bath should be shortened or a supplementary hot bath may be applied after the cold bath. The best combination in any instance will vary with the character and the condition of the timber and must be learned by trial. The penetration cannot always be controlled at will by manipulating the treating conditions, however, for some woods are highly resistant to treatment and at best may permit a penetration of only one-eighth inch or less, especially in heartwood faces. The sapwood of most species is less resistant to penetration than the heartwood and hence penetrations of one-fourth to 1 inch are often obtained in sapwood.

STEEPING PROCESS

Although the steeping process is old and has been employed in Europe for many years, its use in the United States has not been extensive. Its usefulness is very limited.[43] When mercuric chloride is employed as the preservative, which is most common, the process is called kyanizing or the kyan process. Zinc chloride, sodium fluoride, and other water-soluble preservatives may also be used.

In treating by the steeping process, the timber is simply submerged in the unheated preservative solution and allowed to soak, usually for about a week. A longer soaking period would result in better absorption and penetration of the preservative, and when time is not an important factor it is advisable to soak for 2 weeks. When time is very limited the timber can be removed from the solution after 2 or 3 days, and fairly good results may be expected. The penetrations obtained are likely to vary from as little as one-sixteenth of an inch to as much as 1-inch, depending on the resistance of the wood being treated.

If the lumber to be treated has flat surfaces and is closely piled the solution may not easily come into contact with all parts of each piece. It is important, with all sawed material, therefore, to use stickers one-half inch or more in thickness between adjacent boards. When mercuric chloride is used, the tank must be made of a noncorroding material or must have special protection against corrosion.

A solution strength of about 1 percent is common with mercuric chloride. For zinc chloride 5 percent, and for sodium fluoride 3½-percent solutions are recommended.

DIPPING PROCESS

The dipping process (Hunt), which is used with creosote and similar preservatives, consists simply in submerging the wood in the hot preservative for a short time, usually from 5 to 15 minutes, and then

[43] WIRKA, R. M. PRESERVATION OF TIMBER BY THE STEEPING PROCESS. U. S. Dept. Agr. Forest Products Lab. R621, 7 pp. 1933. [Mimeographed.]

removing it and allowing the excess oil to drain back into the tank. The temperature of the oil should be 200° to 230° F., and the wood should be thoroughly seasoned and dry on the surface. In cold weather a longer dipping period should be used. Wood should not be dipped while covered with frost, snow, or rain water, since the water on the surface will interfere with the absorption of oil.

The effectiveness of the dipping treatment is limited and the process should not be used unless better methods are out of the question. The amount of oil absorbed will depend upon the timber and upon the length of the treating period. Ordinarily, however, it will probably be about 10 to 15 gallons per 1,000 surface feet. The penetration obtained in exceptional instances may be from one-eighth to one-fourth inch, but ordinarily it will be one-sixteenth inch or less. The dipping process gives greater assurance than brushing or spraying that all surfaces have been thoroughly coated with the oil and should result in slightly greater penetrations.

BRUSH TREATMENT AND SPRAYING

The simplest and usually least effective treatment is to apply the preservative to the wood with a brush or a spray nozzle (Hunt). Creosote and similar oils, preferably hot, are used in this treatment. Heating is sometimes inconvenient, however, and the oil is often applied cold. In such event creosote oil that is thoroughly liquid when cold should be selected. The oil should be flooded over the wood, rather than merely painted upon it, and care should be taken to see that every check and depression in the wood is thoroughly filled with the preservative, since any untreated wood left exposed provides ready access for fungi. At least two coats should be applied, the second one after the first has dried. This may require as much as 10 gallons of oil to 1,000 square feet of surface on rough lumber, although considerably less on surfaced lumber. The penetrations obtained will usually be less than one-sixteenth of an inch.

Brush treatment with water-soluble preservatives is not worth while for wood that is exposed to the weather or to water, and is less likely than creosote brush treatment to be effective in protected situations.

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POLES, PILING, AND TIES

PRINCIPAL SPECIES USED FOR POLES

Following are the more important factors considered in selecting species for poles:

(1) Durability. Poles should be of a naturally durable wood or treated, since decay, which takes place most rapidly at or near the ground line where the wood is alternately wet and dry, is the principal cause of replacement.

(2) Weight. Lightness is desirable from the standpoint of shipping costs and ease of handling and erecting.

(3) Strength. Poles must be sufficiently strong to withstand the weight of the wire, ice coatings on the wires, and wind pressure.

(4) Form. The poles should be reasonably straight, with a gradual taper and with the defects limited so as to insure sufficient strength. The good appearance resulting from smoothness, straightness, and uniform taper are particularly desirable in urban districts.

The principal species used for poles in electric-communication and power-transmission-and-distribution lines are the cedars, southern yellow pine, chestnut, and cypress.

CEDARS

Western red, northern white, southern white, and eastern red cedars are extensively used for poles. The cedars have comparatively thin sapwood, and the heartwood is naturally decay resistant. Western red cedar is the most extensively used of the cedars for poles. Northern white cedar is next. Southern white cedar and eastern red cedar furnish a relatively small number of poles. The Lake States furnish most of the northern white cedar poles, and Idaho, Washington, and British Columbia most of the western red cedar poles. The butts of western red, northern white, and southern white cedar poles are usually treated with creosote to increase the durability of the sapwood. The sapwood of eastern red cedar is so thin and the heartwood so durable that poles of this species are generally used without treatment. It is, however, more difficult to obtain in pole sizes than the other cedars.

SOUTHERN YELLOW PINE

The yellow pines from the South are extensively used for poles. The diminishing supply of northern white cedar, and the freight cost of the long haul for western red cedar to the eastern and southern parts of the United States are factors in the increased use of southern yellow pine. Southern pine poles require full-length pressure treatment, usually with creosote, since their life would be comparatively short without it. The cedars and the southern pines together now furnish about 90 percent of the wooden poles.

CHESTNUT

Chestnut was for many years a favorite pole timber in the Northeast and along the Atlantic seaboard. Its moderately light weight and natural durability make it a good pole timber, but its shape is less desirable than that of most other pole timbers. Chestnut is next in importance to southern yellow pine and cedar for poles but furnishes less than 10 percent of the total.

CYPRESS

Cypress poles have good form but owing to the large amount of sapwood in the trees of pole size it is necessary to treat them adequately with creosote if good service is to be obtained.

OTHER SPECIES

Douglas fir, oak, redwood, and lodgepole pine are used to some extent for poles.

The use of Douglas fir has been limited, chiefly because of the ample supply of western red cedar, which is logged in the same region and is higher in natural decay resistance. Cedar is usually given butt treatment only, whereas Douglas fir is given full-length treatment. Douglas fir is used to some extent on the Pacific coast, especially where full-length treatment is desired as protection from dry-wood termites. It is stronger than the cedar but heavier.

The lightness and durability of redwood make it a desirable pole material. Most of the redwood trees, however, are too large for poles and hence must be sawed into suitable sizes, which materially increases the cost. Round redwood poles from small trees, selected for thin sapwood, are used to some extent. Rapidly grown redwood trees with thick sapwood are not sufficiently durable without full-length preservative treatment. Redwood poles are used mostly locally.

The use of oak poles is limited to rural telephone lines and the like where short poles are satisfactory. White oak is preferable to red oak on account of its greater natural resistance to decay, but neither will give long life without adequate preservative treatment. Oak poles are heavy and frequently crooked. The freight costs and the value of oak for other purposes prohibit any wide distribution of the larger-sized poles.

Lodgepole pine is being used to an increasing extent in the Rocky Mountain region because of its desirable shape, susceptibility to preservative treatment, and availability. Throughout most of this region decay in the tops of poles is not rapid and butt treatment only is required. The natural decay resistance of lodgepole pine is too low to permit satisfactory service without treatment.

Other species used to a slight extent and for the most part locally include tamarack, spruce, hemlock, black locust, ash, elm, and cottonwood. With the exception of black locust none of these last very long without preservative treatment.

WEIGHT OF SPECIES USED FOR POLES

The weight of poles is an important factor in freight charges and, except where machines are used, in the ease of handling and erecting. Table 51 gives the weights per cubic foot for the more important pole woods grown in the United States.

TABLE 51.—*Weight per cubic foot and specific gravity of the more important species used for poles*

Species	Green	Air dry (12-percent moisture content)	Specific gravity oven dry [1]	Species	Green	Air dry (12-percent moisture content)	Specific gravity oven dry [1]
	Lb. per cu. ft.	*Lb. per cu. ft.*			*Lb. per cu. ft.*	*Lb. per cu. ft.*	
Cedar:				Oak:			
Eastern red	37	33	0.44	Red	64	44	0.57
Northern white	28	22	.29	White	63	47	.59
Southern white	26	23	.31	Pine:			
Western red	27	23	.31	Loblolly	53	36	.47
Chestnut	55	30	.40	Lodgepole	39	29	.38
Cypress: Southern	51	32	.42	Longleaf	55	41	.54
Douglas fir:				Shortleaf	52	36	.46
Coast region	38	34	.45	Redwood	50	28	.38
Mountain region	35	30	.40				

[1] Based on volume when green.

VOLUME OF POLES AND PILES

Volumes of poles or piles may be computed by measuring the lengths and diameters and applying a formula or a volume table.

The values in table 52 were computed by the cone-frustum formula

$$V = 0.2618L\frac{(D^2+d^2+dD)}{144}$$

where V is the volume in cubic feet, L the length in feet, D the top diameter in inches, and d the butt diameter in inches.

The values are accurate for pieces of uniform taper and circular cross section. Errors from irregularities of shape and taper may be minimized by taking diameter measurements at short intervals and computing the volume of each short section separately.

ULTIMATE FIBER STRESSES FOR WOODEN POLES

Standard values of ultimate fiber stress in bending for poles, approved by the American Standards Association and incorporated in the National Electrical Safety Code (Bureau of Standards, both references),[44] are as follows:

Species:	*Pounds per square inch*
Northern white cedar	3,600
Western red cedar	5,600
Chestnut	6,000
Douglas fir (creosoted)	7,400
Lodgepole pine (creosoted)	6,600
Southern yellow pine (creosoted)	7,400

[44] For further information, the reference list at the end of this section should be consulted.

TABLE 52.—*Cubical contents of poles or piling*

[Find the average diameter at each end of the piece to the nearest half inch. Multiply the number in the table corresponding to these two diameters by the length of the piece in feet. The result is in cubic feet]

Large diameter (inches)	Cubic feet per lineal foot when the small diameter in inches is—																	
	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
6	0.14	0.15	0.17	0.18															
6.5	.15	.17	.18	.20	0.21														
7	.17	.18	.20	.21	.23	0.25													
7.5	.19	.20	.22	.23	.25	.27	0.29												
8	.20	.22	.23	.25	.27	.29	.31	0.33											
8.5	.22	.24	.25	.27	.29	.31	.33	.35	0.37										
9	.24	.26	.27	.29	.31	.33	.35	.37	.39	0.42									
9.5	.26	.28	.30	.31	.33	.35	.37	.40	.42	.44	0.47								
10	.28	.30	.32	.34	.36	.38	.40	.42	.44	.47	.49	0.52							
10.5	.31	.32	.34	.36	.38	.40	.42	.45	.47	.49	.52	.55	0.57						
11	.33	.35	.37	.38	.41	.43	.45	.47	.50	.52	.55	.57	.60	0.63					
11.5	.35	.37	.39	.41	.43	.45	.48	.50	.52	.55	.58	.60	.63	.66	0.69				
12	.38	.40	.42	.44	.46	.48	.50	.53	.55	.58	.61	.63	.66	.69	.72	0.75			
12.5	.40	.42	.44	.46	.49	.51	.53	.56	.58	.61	.64	.66	.69	.72	.75	.79	0.82		
13	.43	.45	.47	.49	.51	.54	.56	.59	.61	.64	.67	.70	.73	.76	.79	.82	.85	0.89	
13.5	.46	.48	.50	.52	.54	.57	.59	.62	.64	.67	.70	.73	.76	.79	.82	.85	.89	.92	0.96
14	.49	.51	.53	.55	.57	.60	.62	.65	.68	.70	.73	.76	.79	.82	.86	.89	.92	.96	.99
14.5	.52	.54	.56	.58	.61	.63	.66	.68	.71	.74	.77	.80	.83	.86	.89	.93	.96	1.00	1.03
15	.55	.57	.59	.61	.64	.66	.69	.72	.74	.77	.80	.83	.86	.90	.93	.96	1.00	1.03	1.07
15.5	.58	.60	.62	.65	.67	.70	.72	.75	.78	.81	.84	.87	.90	.93	.97	1.00	1.04	1.07	1.11
16	.61	.63	.66	.68	.71	.73	.76	.79	.81	.84	.87	.91	.94	.97	1.01	1.04	1.08	1.11	1.15
16.5	.64	.67	.69	.71	.74	.77	.79	.82	.85	.88	.91	.94	.98	1.01	1.04	1.08	1.12	1.15	1.19
17	.68	.70	.73	.75	.78	.80	.83	.86	.89	.92	.95	.93	1.02	1.05	1.09	1.12	1.16	1.20	1.23
17.5	.71	.74	.76	.79	.81	.84	.87	.90	.93	.93	.99	1.02	1.05	1.09	1.13	1.16	1.20	1.24	1.23
18	.75	.77	.80	.82	.85	.88	.91	.94	.97	1.00	1.03	1.03	1.10	1.13	1.17	1.21	1.24	1.28	1.32
18.5	.79	.81	.84	.86	.89	.92	.95	.98	1.01	1.04	1.07	1.11	1.14	1.18	1.21	1.25	1.29	1.33	1.37
19	.82	.85	.87	.90	.93	.96	.99	1.02	1.05	1.08	1.11	1.15	1.18	1.22	1.26	1.29	1.33	1.37	1.41
19.5	.86	.89	.91	.94	.97	1.00	1.03	1.06	1.09	1.12	1.16	1.19	1.23	1.26	1.30	1.34	1.38	1.42	1.46
20	.90	.93	.95	.98	1.01	1.04	1.07	1.10	1.13	1.17	1.20	1.24	1.27	1.31	1.35	1.39	1.43	1.47	1.51

POLE DIMENSION TABLES

The dimensions of poles are specified in two ways, namely, by stating the length and the size required at the ground line together with a minimum size at the top, or by specifying only the length and the size at the top, assuming that the taper is sufficiently great to give the needed size at the ground line (Eggleston and Jahn). These two methods have resulted in two general types of dimension tables, (1) class tables, in which the classification is based on both top and ground-line dimensions, and (2) top-dimension tables, in which the poles are classified by top sizes only. Purchasing by top size only is the simpler; but as the taper of different poles even of the same species varies, two poles of the same top diameter may differ considerably in diameter at the ground line. This may result in large differences in the bending strength, which varies as the cube of the diameter. There is still a considerable demand for top-dimension poles although most large users purchase class poles.

The standard dimensions for wooden poles given in table 53 were developed by the American Standards Association in 1931 in order to meet the engineering requirements of pole users with a minimum number of classes and lengths. A pole is specified by its class, length, and species. Ten classes are provided, the first seven of which are so dimensioned that the computed horizontally acting breaking load for a pole of a given class is the same regardless of its length or species. The compressive stress in a pole due to vertical load, even when the wires are heavily coated with ice, is primarily of little con-

TABLE 53.—*American standard dimensions for wood poles of different minimum circumferences at 6 feet from the butt*

Length of pole (feet)	Ground-line distance from butt	Butt size for poles of the class and minimum top circumference indicated [1] of— Creosoted southern pine							Western red cedar						
		Class 1, 27 inches	Class 2, 25 inches	Class 3, 23 inches	Class 4, 21 inches	Class 5, 19 inches	Class 6, 17 inches	Class 7, 15 inches	Class 1, 27 inches	Class 2, 25 inches	Class 3, 23 inches	Class 4, 21 inches	Class 5, 19 inches	Class 6, 17 inches	Class 7, 15 inches
	Ft.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
16	3½	------	------	------	------	21.5	19.5	18.0	------	------	------	------	23.0	21.5	19.5
18	3½	------	------	26.5	24.5	22.5	21.0	19.0	------	------	28.5	26.5	24.5	22.5	21.0
20	4	31.5	29.5	27.5	25.5	23.5	22.0	20.0	34.5	32.0	30.0	28.0	25.5	23.5	22.0
22	4	33.0	31.0	29.0	26.5	24.5	23.0	21.0	36.0	33.5	31.5	29.0	27.0	25.0	23.0
25	5	34.5	32.5	30.0	28.0	26.0	24.0	22.0	38.0	35.5	33.0	30.5	28.5	26.0	24.5
30	5½	37.5	35.0	32.5	30.0	28.0	26.0	24.0	41.0	38.5	35.5	33.0	30.5	28.5	26.5
35	6	40.0	37.5	35.0	32.0	30.0	27.5	25.5	43.5	41.0	38.0	35.5	32.5	30.5	28.0
40	6	42.0	39.5	37.0	34.0	31.5	29.0	27.0	46.0	43.5	40.5	37.5	34.5	32.0	------
45	6½	44.0	41.5	38.5	36.0	33.0	30.5	28.5	48.5	45.5	42.5	39.5	36.5	------	------
50	7	46.0	43.0	40.0	37.5	34.5	32.0	29.5	50.5	47.5	44.5	41.0	38.0	------	------
55	7½	47.5	44.5	41.5	39.0	36.0	33.5	------	52.5	49.5	46.0	42.5	39.5	------	------
60	8	49.5	46.0	43.0	40.0	37.0	34.5	------	54.5	51.0	47.5	44.0	------	------	------
65	8½	51.0	47.5	44.5	41.5	38.5	------	------	56.0	52.5	49.0	45.5	------	------	------
70	9	52.5	49.0	46.0	42.5	39.5	------	------	57.5	54.0	50.5	47.0	------	------	------
75	9½	54.0	50.5	47.0	44.0	------	------	------	59.5	55.5	52.0	48.5	------	------	------
80	10	55.0	51.5	48.5	45.0	------	------	------	61.0	57.0	53.5	49.5	------	------	------
85	10½	56.5	53.0	49.5	------	------	------	------	62.5	58.5	54.5	------	------	------	------
90	11	57.5	54.0	50.5	------	------	------	------	63.5	60.0	56.0	------	------	------	------

Length of pole (feet)	Ground-line distance from butt	Chestnut							Northern white cedar						
		Class 1, 27 inches	Class 2, 25 inches	Class 3, 23 inches	Class 4, 21 inches	Class 5, 19 inches	Class 6, 17 inches	Class 7, 15 inches	Class 1, 27 inches	Class 2, 25 inches	Class 3, 23 inches	Class 4, 21 inches	Class 5, 19 inches	Class 6, 17 inches	Class 7, 15 inches
	Ft.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
16	3½	------	------	------	------	22.5	21.0	19.5	------	------	------	------	26.0	24.0	22.0
18	3½	------	------	28.0	26.0	24.0	22.0	20.5	------	------	32.5	30.0	28.0	25.5	23.5
20	4	33.5	31.5	29.5	27.0	25.0	23.0	21.5	39.5	37.0	34.0	31.5	29.0	27.0	25.0
22	4	35.0	33.0	30.5	28.5	26.5	24.5	22.5	41.0	38.5	36.0	33.0	30.5	28.0	26.0
25	5	37.0	34.5	32.5	30.0	28.0	25.5	24.0	43.5	41.0	38.0	35.5	32.5	30.0	28.0
30	5½	40.0	37.5	35.0	32.5	30.0	28.0	26.0	47.5	44.5	41.5	38.5	35.5	33.0	30.5
35	6	42.5	40.0	37.5	34.5	32.0	30.0	27.5	50.5	47.5	44.0	41.0	38.0	35.0	32.5
40	6	45.0	42.5	39.5	36.5	34.0	31.5	29.5	53.5	50.0	46.5	43.5	40.0	37.0	------
45	6½	47.5	44.5	41.5	38.5	36.0	33.0	31.0	56.0	52.5	49.0	45.5	42.0	------	------
50	7	49.5	46.5	43.5	40.0	37.5	34.5	32.0	58.5	55.0	51.5	47.5	44.0	------	------
55	7½	51.5	48.5	45.0	42.0	39.0	36.0	------	61.0	57.5	53.5	49.5	46.0	------	------
60	8	53.5	50.0	46.5	43.5	------	------	------	63.5	59.5	55.5	51.5	------	------	------
65	8½	55.0	51.5	48.0	45.0	------	------	------	------	------	------	------	------	------	------
70	9	56.5	53.0	------	------	------	------	------	------	------	------	------	------	------	------

Length of pole (feet)	Ground-line distance from butt	Creosoted lodgepole pine						
		Class 1, 27 inche	Class 2, 25 inches	Class 3, 23 inches	Class 4, 21 inches	Class 5, 19 inches	Class 6, 17 inches	Class 7, 15 inches
	Ft.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
16	3½	----------	----------	----------	----------	22.0	20.5	19.0
18	3½	----------	----------	27.5	25.5	23.5	21.5	20.0
20	4	32.5	30.5	28.5	26.5	24.5	22.5	21.0
22	4	34.0	32.0	30.0	27.5	25.5	23.5	22.0
25	5	36.0	33.5	31.0	29.0	27.0	25.0	23.0
30	5½	39.0	36.5	34.0	31.5	29.0	27.0	26.5
35	6	41.5	38.5	36.0	33.5	31.0	28.5	28.0
40	6	44.0	41.0	38.0	35.5	33.0	30.5	25.0
45	6½	46.0	43.0	40.0	37.0	34.5	32.0	29.5
50	7	48.0	45.0	42.0	39.0	36.0	33.5	31.0
55	7½	49.5	46.5	43.5	40.5	37.5	34.5	----------
60	8	51.5	48.0	45.0	42.0	38.5	----------	----------
65	8½	53.0	49.5	46.0	43.0	----------	----------	----------
70	9	54.5	51.0	47.5	----------	----------	----------	----------
75	9½	56.0	52.5	----------	----------	----------	----------	----------

[1] No butt requirements for poles of classes 8, 9, and 10 that have minimum top circumferences of 18, 15, and 12 inches, respectively.

sequence, and the controlling element in the strength of a pole is its resistance to horizontal wind forces on the wires or the horizontal pull of dead-end or unbalanced wires. The vertical load also causes bending stress when the pole is deflected by horizontal forces. The remaining three classes are based solely on top circumferences.

The loads, which if applied 2 feet from the top end of the pole will develop the specified ultimate bending stress at the ground line of a pole set to the assumed depth (listed in table 53 as "ground line distances from butt"), are as follows:

Class:	*Pounds*	Class:	*Pounds*
1	4,500	5	1,900
2	3,700	6	1,500
3	3,000	7	1,200
4	2,400		

The assumed depths of setting as given in table 53 are general averages from which it is expected that variations will be made in accordance with soil conditions.

The loads and stresses previously quoted and the dimensions given in table 53 apply to poles with defects limited as provided in specifications approved as tentative standards by American Standards Association (six references) and Colley and Eggleston.

PRESERVATIVE TREATMENT

When butt treatment only is required poles are usually treated with coal-tar creosote by the hot-and-cold-bath open-tank process described on page 279. Dipping or brush treating the butts of poles gives a slight increase in life but not nearly so much as is obtained through the use of more thorough methods of treatment.

In cedar poles the best penetration is obtained by incising them before treatment. Specifications covering the hot-and-cold-bath treatment of cedar poles with or without incising have been adopted by the American Wood Preservers' Association (second reference).

Lodgepole pine poles do not require incising for butt treatment by hot-and-cold bath since they have deeper sapwood than cedar and are less resistant to penetration. The only specifications in use for the butt treatment of this species are those prepared by individual treating plants or purchasers.

Southern yellow pine and Douglas fir poles are usually given full-length, empty-cell, pressure treatment with coal-tar creosote. A minimum absorption of 8 pounds of coal-tar creosote per cubic foot of wood by an empty-cell process is commonly specified. Absorptions of 10 or 12 pounds per cubic foot are frequently specified especially in the South. The higher absorptions cost more but will give greater assurance of satisfactory penetration and long life. Specifications covering the pressure treatment of these woods have been adopted by the American Wood Preservers' Association (third reference).

Some creosoted poles exude oil sufficiently to make the surface oily in spots. This bleeding is not likely to affect the life of the poles but it may prove objectionable to men who work on the poles or, in urban territory, to anyone who may come in contact with a pole that is bleeding. Methods of completely preventing bleeding have not been estab-

lished, but progress in this direction is being made. Unnecessarily high absorptions and the use of tar or petroleum mixtures are to be avoided when freedom from bleeding is paramount.

Water-borne preservatives are not extensively used for pole treatment but have been employed to some extent. Poles so treated are cleaner than creosoted poles but cannot be expected to last so long.

A considerable number of poles in the Rocky Mountain and North Pacific coast regions have been treated by placing crude arsenic or "cold treater dust" in the bottom of the hole and in rings around the pole as the dirt is replaced. The results have not been entirely satisfactory. A modified treatment now used is to apply the arsenic in the form of a paste to the entire surface of the part of the pole below the ground. It is still too early to determine how effective this will be. A process has been devised in Germany that consists in forming a blanket of fibrous material and preservative and fastening this around the pole at the places to be protected. Water from the soil is counted upon to distribute the preservative. The process is too new to have had time to demonstrate its effectiveness.

TREATMENT TO STOP DECAY IN STANDING POLES

Poles in service that have started to decay are sometimes treated to arrest the decay and extend their life. The method that has been most used in the United States is to dig away the earth from around the pole to a depth of 1 to 1½ feet, scrape away all decayed wood, allow the exposed wood to air dry for several days, char it with a blow torch, and spray hot creosote upon the charred surface. The process is patented in Sweden and the United States. The charring is omitted as unnecessary by one large pole-using company. If the work is well done the life of poles having sound centers should be extended more than enough to make the treatment pay, but detailed figures are not available on the additional life obtained and the financial savings that result. Poles having rot at the center under a shell of good wood will not be appreciably benefited.

Another method of stopping the decay in standing poles is to drive a heavy hollow needle into the wood and then force water-soluble preservative in paste form into the wood as the needle is withdrawn. The holes are made at suitable distances apart over the ground section, where the decay hazard is greatest, so that the moisture in the wood may distribute the preservative throughout the cross section. This method under the name "Cobra Process" has been used for 8 or 10 years in Germany, and conflicting reports as to its efficiency have been received. A similar method is being promoted under the name "Pfister Process." It appears to have merit but has not been used in the United States sufficiently to demonstrate its effectiveness or economy.

LIFE OF POLES

The life of poles is so greatly influenced by their size and amount of sapwood, the soil, climatic and use conditions, the character of preservative treatment, and the loads carried, that average life figures are not very reliable, and wide variations from the average are to be expected in individual installations. Service records are not

available in sufficient quantity to determine a mathematical average. Roughly, it may be said that average-sized poles of untreated northern white cedar, western red cedar, Port Orford cedar, redwood, cypress, and chestnut, when the sapwood is less than an inch in thickness, will last about 12 to 15 years without treatment. Good butt treatment with creosote will increase the life to 20 years or more in territory where failure from top decay is infrequent and dry-wood termites are not active. Poles of cypress, Port Orford cedar, and redwood may have sapwood much thicker than 1 inch, in which event their life untreated will be greatly reduced. The decay resistance of black locust and eastern red cedar poles having thin sapwood is so high that a life of 20 years may be expected. Treatment of these woods is usually unnecessary. In one experiment with untreated southern white cedar poles an average life of about 7.5 years was obtained, but it is not at all certain that this is a representative figure. Douglas fir and tamarack poles, when used untreated, are likely to last only about 8 years or less. Southern pine poles used without treatment under the warm, damp conditions prevailing throughout most of the Southern States would be likely to fail in a year or two. On the other hand, with an absorption of 10 pounds or more of creosote thoroughly injected by an empty-cell process, southern pine poles of good quality should last 25 years or more. As good results can be expected with similarly treated Douglas fir. In the Rocky Mountain region lodgepole pine with a thorough butt treatment with coal-tar creosote should have an average life of 20 years or more, but this species would require full-length treatment in any place where decay in sapwood above the ground line is common.

CHOICE OF SPECIES FOR PILING

The properties desirable in piles include sufficient strength and straightness to withstand driving and to carry the weight of structures built on them, and in some instances to resist bending stresses. Decay resistance or ease of penetration by preservatives is also important except in piles for temporary use or piles that will be in fresh water entirely below the permanent water level.

Douglas fir, southern yellow pine, and oak are among the principal species used for piling requiring high strength. Lighter weight species, such as western red cedar, are sometimes used where driving resistance is moderate. Numerous other species are also used when strength or durability requirements are not exacting.

Specifications for timber piles covering kinds of wood, general quality, resistance to decay, dimensions, tolerance, manufacture, inspection, delivery, and shipment have been published in the American Railway Engineering Association Manual. Specifications for timber piles have also been prepared by the American Association of State Highway Officials and the American Society for Testing Materials.

BEARING LOADS FOR PILES

Piles are classified into the following two groups, depending on how the load is sustained: (1) The pile tip rests on a solid stratum by which the load is carried and there is little or no friction along

its sides; (2) the pile receives practically all its support from earth friction along its sides (Goodrich; Merriman, pp. 730–741; Terzaghi).

Piles in group 1 are considered as columns and designed accordingly (p. 162). The strength of those piles in group 2 in which a large proportion of their length extends above the ground must also be considered on the basis of long columns. In such an instance, however, bracing to reduce the unsupported length is usually possible.

The determination of the load-carrying capacity of piles classed in group 2 is a subject on which there is considerable diversity of opinion among engineers. The Forest Products Laboratory has made no special study of pile formulas or methods of determining the load capacity of wood piles from records of their behavior in driving. Many experienced engineers have little faith in any formula for bearing capacity of piles and advocate basing design in each instance on experience and observation of the behavior of pile foundations under similar conditions or on results of static loading tests (American Railway Engineering Association, second reference; Granholm; Hiley; and Wellington, two references). A discussion of the various formulas given in engineering handbooks and other literature is, therefore, beyond the scope of the present handbook.

ECCENTRIC LOADING AND CROOKED COLUMNS

The reduction in strength of a wooden column resulting from crooks, eccentric loading, or any other condition that will result in combined bending and compression is not so great as might be expected. Tests have shown that a timber, when subjected to combined bending and compression, develops a higher stress at both the elastic limit and maximum load than when subjected to compression only (Newlin and Trayer). This does not imply that crooks and eccentricity should be without restriction, but it should relieve anxiety as to the influence of crooks such as those common in piling.

DRIVING OF PILES AS AFFECTED BY SEASONING

The usual conditions of service are such that a pile in place will be wet. However, because of the increased strength resulting from drying, seasoned piles either treated or untreated are likely to stand driving better than are green or unseasoned ones. This is particularly true of treated piles inasmuch as tests have demonstrated that while the strength of green wood may be considerably reduced by treatment, after thorough seasoning treated wood may be but little weaker than untreated wood. Under the same drying conditions, however, untreated material loses moisture more rapidly than does treated material.

It is often necessary for piles to be cut, treated, and placed within so short a period that sufficient drying to affect their strength is impossible. In such instances, special care in driving is advisable.

Other advantages of seasoning are given on page 203.

DECAY RESISTANCE AND PRESERVATIVE TREATMENT OF PILING

Piling are cut from small trees which, in the majority of species, have rather wide sapwood and consequently low decay resistance. High natural decay resistance will be found only when the piles have thin sapwood and are of species that have decay-resistant heartwood (p. 41).

Since wood that remains completely submerged in water does not decay, decay resistance is not necessary in piling so used, but it is necessary in any part of the piling that may extend above the permanent water level. When piling that supports the foundations of bridges or buildings is to be cut off above the permanent water level it should, as a safety precaution, be pressure creosoted usually by the empty-cell process, with not less than 12 pounds of creosote per cubic foot (American Railway Engineering Association Manual and American Wood Preservers' Association, first reference). The untreated surfaces exposed at the cut-offs should also be given protection, as indicated on page 274.

Piling driven into earth that is not constantly wet is subject to about the same service conditions as apply to poles, has similar life, and requires similar protection.

Piling used in salt water is, of course, subject to destruction by marine borers even though it does not decay below the water line. Methods of creosoting against marine borers are discussed on pages 260 and 261.

STRENGTH REQUIREMENTS FOR TIES

Many species of wood are used for ties. Their relative suitability depends largely upon their strength, wearing qualities, susceptibility to preservative treatment, and to some extent their natural resistance to decay and tendency to check, although availability and cost must also be considered.

The chief strength properties considered in a wood for crossties are (1) bending strength, (2) end hardness and strength in compression parallel to grain, which are indicative of resistance to spike pulling and the lateral thrust of spikes, and (3) side hardness and compression perpendicular to the grain, which indicate resistance to wear under the rail or the tieplate.

To compare the relative strength of different species consult table 8. The composite tie-strength figures given in table 54 consist of a combination of the strength properties listed above as necessary for satisfactory service (Markwardt). Average values of specific gravity are also given. Table 54 shows that a species of high specific gravity usually has a high composite tie-strength value, and hence in the absence of other strength data the specific gravity is a good criterion.

The relative importance of the several mechanical properties involved for ties changes with conditions of track installation and maintenance and with service conditions. For example, the requirements for ties under heavy traffic will be greatly different than for light traffic. Consequently the composite tie values should be regarded as indicative, rather than an exact measure of the relative mechanical suitability of species for crossties.

TABLE 54.—*Composite-strength figures and specific-gravity values of crosstie woods*

Species	Composite-strength figure	Specific gravity [1]
Ash, commercial white	108	0.54
Aspen	46	.35
Largetooth	53	.35
Beech	97	.56
Birch:		
Sweet	108	.60
Yellow	94	.55
Catalpa, hardy	52	.38
Cedar:		
Eastern red	78	.44
Northern white	40	.29
Port Orford	67	.40
Western red	52	.31
Cherry:		
Black	84	.47
Pin	52	.36
Chestnut	59	.40
Cottonwood:		
Black	45	.32
Eastern	49	.37
Cypress, southern	68	.42
Douglas fir:		
Coast	78	.45
Inland Empire	71	.41
Rocky Mountain	65	.40
Elm:		
American	73	.46
Rock	103	.57
Slippery	81	.48
Fir, commercial white	58	.36
Gum:		
Black	79	.46
Red	71	.44
Tupelo	81	.46
Hackberry	74	.49
Hemlock:		
Eastern	63	0.38
Western	64	.38
Hickories:		
Pecan	127	.59
True	141	.65
Larch, western	80	.48
Locust:		
Black	161	.66
Honey	133	.60
Maple:		
Silver	67	.44
Sugar	112	.56
Oak:		
Commercial red	100	.57
Commercial white	103	.59
Pine:		
Jack	58	.39
Loblolly	73	.47
Lodgepole	56	.38
Longleaf	90	.54
Norway	67	.44
Ponderosa	54	.38
Shortleaf	72	.46
Piñon	70	.50
Poplar, Balsam	36	.30
Redwood	72	.38
Sassafras	66	.42
Spruce, Engelmann	44	.31
Spruces (red, Sitka, and white)	57	.37
Sycamore	69	.46
Tamarack	71	.49
Walnut, black	100	.51

[1] Based on volume when green, and weight when oven dry.

DECAY RESISTANCE AND PRESERVATIVE TREATMENT OF TIES

Although the majority of ties used are given preservative treatment before installation, many are used untreated, and for these natural decay resistance (p. 41) is important. In ties given preservative treatment, variations in natural decay resistance are of less importance than susceptibility to treatment.

The majority of ties treated are pressure treated with coal-tar creosote, creosote-coal-tar solutions, or creosote-petroleum mixtures. Absorptions of 6 to 8 pounds per cubic foot, injected by an empty-cell process, are most commonly employed. The higher absorption is recommended.

Zinc chloride is next in importance to creosote and its mixtures for tie treatments. The absorption most commonly used is one-half pound of the dry preservative per cubic foot of wood, injected by the full-cell process, but absorptions of three-fourths or 1 pound are preferable. Zinc chloride and creosote mixtures are used to some extent. Other preservatives are used for ties to a slight extent only.

Specifications covering the preservative treatment of ties have been adopted and published by the American Wood Preservers' Association (third reference) and the American Railway Engineering Association Manual.

LIFE OF TIES

The life of ties in service depends on their ability to resist decay and the extent to which they are protected from mechanical destruction by breakage, loosening of spikes, and rail or plate wear. Under sufficiently light traffic, heartwood ties of naturally durable wood even if of low strength may give 10 or 15 years' service without preservative treatment, but under heavy traffic without adequate mechanical protection the same ties might fail through mechanical wear in 2 or 3 years. The life of treated ties is affected also by the preservative used and the thoroughness of treatment. As a result the life of individual groups of ties may vary widely from the general average depending on the local circumstances. With these limitations the following rough estimates are given.

Ties well penetrated with 8 pounds or more per cubic foot of coal-tar creosote, creosote-petroleum mixture, or creosote-coal-tar solution should last 20 years or more when protected against mechanical destruction. Ties treated with zinc chloride should last 10 to 15 years except in very wet or very dry climates, where their life would be shorter. Untreated heart ties of cedar, cypress, or redwood, under light traffic conditions may last 12 to 15 years and sometimes longer. Heart ties of Douglas fir, white oak, tamarack, western larch, and southern yellow pine should last 6 to 10 years without treatment. The life of heartwood ties of other species would be generally in accord with their relative standing as indicated on page 41. Regardless of species ties that contain a large proportion of sapwood are not likely to last longer than 2 to 4 years without preservative treatment.

Records on the life of treated and untreated ties are published annually by the American Railway Engineering Association and the American Wood Preservers' Association.

Specifications for crossties covering general quality, resistance to wear, resistance to decay, design, manufacture, inspection, delivery, and shipment have been published in the American Railway Engineering Association Manual.

RELATION BETWEEN PERCENTAGE TIE RENEWALS AND AVERAGE LIFE

If, after the installation of a group of ties, accurate records are kept of the percentage of the group that are removed each year figure 64 can be used to estimate the average life that will be obtained.

There is a fairly definite relation (MacLean) between the rate of renewals and the average life of any particular group of ties of similar quality and subjected to similar conditions of service. The accuracy with which the average life can be predicted by means of figure 64 is greater with large groups of ties than with small groups and increases as the percentage of renewals increases. Since very early renewals are often caused by unsual conditions the average life indicated by renewal percentages below 10 or 15 percent is not so reliable as that indicated by somewhat higher percentages. The average life of a group of ties is usually reached when about 60 percent have been removed.

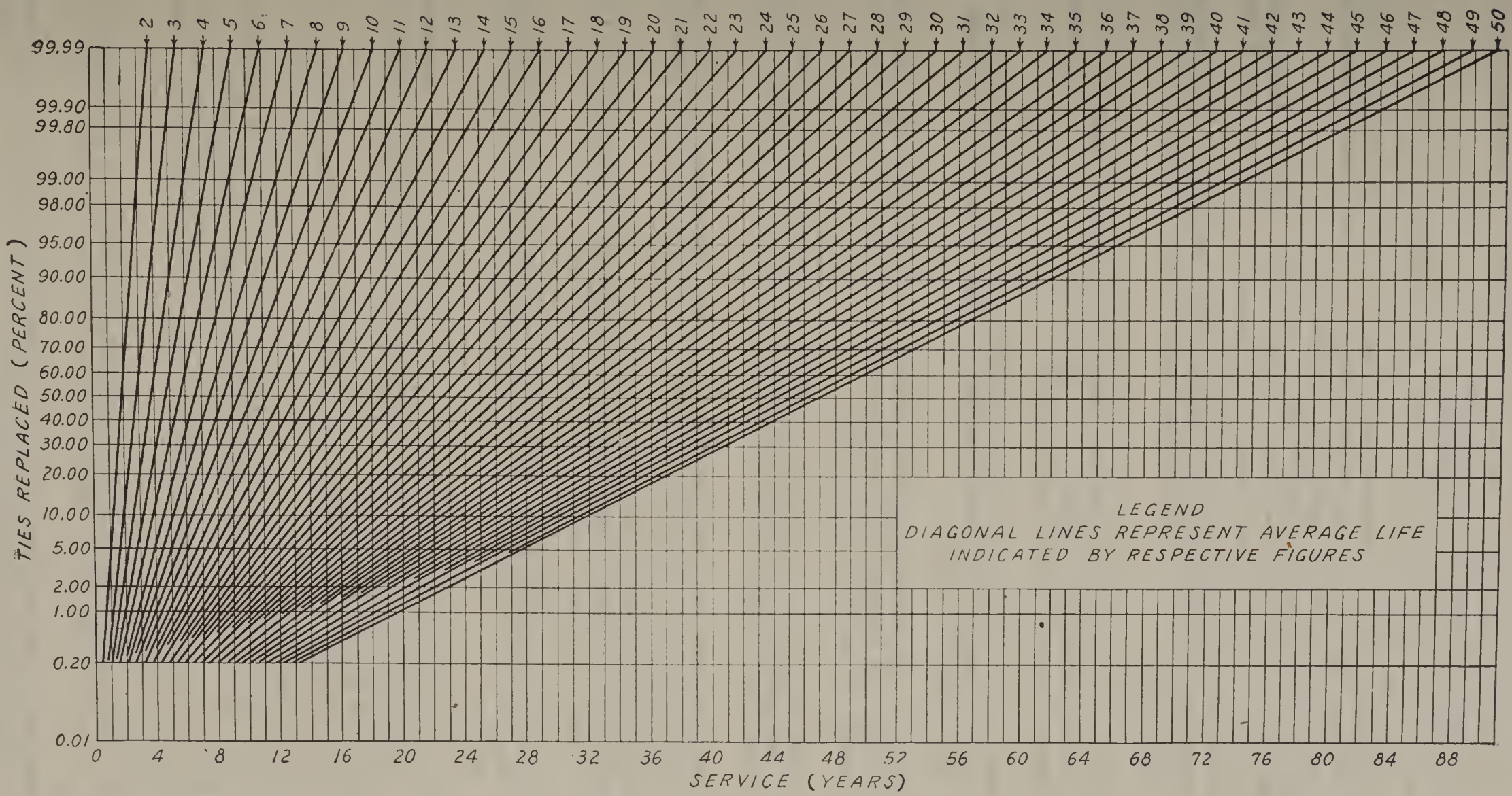


FIGURE 64.—Chart for determining the probable average life of ties from the percentage replaced in a given time. To use the chart find the percentage-renewal figure at the left, follow this line horizontally until it intersects the vertical line corresponding to the number of years the group of ties has been in service, then follow the nearest heavy diagonal line to the upper edge of the chart where the probable average life of the group of ties in years will be found.

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THERMAL INSULATION

The information on thermal insulation is taken entirely from the publications of the Bureau of Standards, United States Department of Commerce, and institutions other than the Forest Products Laboratory. Request for further information should therefore be addressed to the institution designated as the source of information.

INSULATING MATERIALS

The thermal conductivity of a material is an inverse measure of the insulating value of that material. The customary measure of heat conductivity is the amount of heat in British thermal units that will flow in 1 hour through 1 square foot of a layer 1 inch thick of the material under test, per degree Fahrenheit temperature difference between the surfaces of the layer. Exclusive of surface resistances, the insulating value, that is, the resistance to heat flow, of a uniform layer of any substance is generally equal to the thickness of the layer divided by the thermal conductivity of the substance of which the layer is composed.

The same principles that govern insulation against heat are also involved in loss of heat or what is sometimes called insulation against cold.

The insulating value of a material depends somewhat upon the temperatures involved; a given covering, for instance, might be somewhat more effective as house insulation than as oven insulation. Variation in this property, however, is small over the small temperature ranges occurring in buildings. All materials considered here are permeable to water, and an increase in moisture content means a lowering of insulating value. In a wet or thoroughly soaked state the insulating value would be lowered many times; the thermal conductivity of water is about 15 times that of such insulating materials as balsam wool.

Tables 55, 56, and 57 give the thermal conductivities and weights per cubic foot of various commercial products that have been tested at the Bureau of Standards, Armour Institute, or the University of Minnesota (Bureau of Standards Circ. Letter 227).[45] The weights in table 59 do not include the paper or other coverings confining loose materials. In table 57 the conductances and the insulating values of various proprietary products are given in commercial thicknesses. The weights per square foot given in table 57 include the surface coverings, if any are present. In all instances the tabulated values

[45] For further information, the references at the end of this section should be consulted.

are the averages of tests on a number of samples of each material. Since materials of this general class are not always uniform, slight differences in conductivity values have no especial significance.

TABLE 55.—*Thermal conductivity of insulating materials*

(T=mean temperature in degrees Fahrenheit; D=weight in pounds per cubic foot; K=thermal conductivity in British thermal units per hour, and per square foot of conducting material, with a temperature gradient of 1° F. per inch of thickness)

Material		T	D	K	Authority
Name	Description				
Soft flexible materials in sheet form:		° F.	*Lb. per cu. ft.*	*B. t. u.*	
Balsam wool	Chemically treated wood fiber	90	2.2	0.27	Bureau of Standards.
Cabots quilt	Eel grass between kraft paper	90	3.4	.25	Do.
		90	4.6	.26	Do.
Dry zero	Kapok between burlap or paper	90	1.0	.24	Do.
		90	2.0	.25	Do.
Hair felt	Felted cattle hair	90	11.0	.26	Do.
		90	13.0	.26	Do.
Hairinsul	50 percent hair and 50 percent jute.	90	6.1	.26	Do.
Do	75 percent hair and 25 percent jute.	90	6.3	.27	Do.
Keystone hair	Hair felt between layers of paper	75	11.0	.25	Armour Institute.
Linofelt	Flax fibers between paper	90	4.9	.28	Bureau of Standards.
Thermofelt	Hair and asbestos fibers, felted	90	7.8	.28	Do.
Do	Jute and asbestos fibers, felted	90	10.0	.37	Do.
Torfoleum	Peat moss compressed into sheet form.	92	10.2	.29	Do.
Loose materials:					
Calicel	Granular fill insulation made from combined silicate of lime and alumina.	72	4.2	.24	Armour Institute.
Charcoal	From maple, beech, and birch, coarse.	90	13.2	.36	Bureau of Standards.
Do	Passing 6 meshes to the inch	90	15.2	.37	Do.
Do	Passing 20 meshes to the inch	90	19.2	.39	Do.
Glass wool	Pyrex glass, curled	90	4.0	.29	Do.
		90	10.0	.29	Do.
Redwood bark fiber	Shredded redwood bark	94	7.0	.27	J. C. Pebbles.
Regranulated cork	Fine particles	90	9.4	.30	Bureau of Standards.
Do	About 3/16-inch particles	90	8.1	.31	Do.
Rock wool	Fibrous material, made from rock; also made in sheet form, felted and confined with wire netting	90	6.0	.26	Do.
		90	10.0	.27	Do.
		90	14.0	.28	Do.
		90	18.0	.29	Do.
Sawdust	Various	90	12.0	.41	Do.
Do	Redwood	90	10.9	.42	Do.
Shavings	Various, from planer	90	8.8	.41	Do.
Sil-O-Cel	Powdered diatomaceous earth	90	10.6	.31	Do.
Sprayo-Flake	Shredded paper with silica binder.	94	4.2	.28	Do.
Thermofil	Gypsum in powdered form	75	18.0	.34	Armour Institute.
		90	26.0	.52	Bureau of Standards.
		90	34.0	.60	Do.
Semiflexible materials in sheet form:					
Fibrofelt	Flax and rye fiber	90	13.6	.32	Do.
Flaxlinum	Flax fiber	90	13.0	.31	Do.
Semirigid materials in board form:					
Cork board	No added binder; very low density.	90	5.4	.25	Do.
Do	No added binder; low density	90	7.0	.27	Do.
Do	No added binder; medium density.	90	10.6	.30	Do.
Do	No added binder; high density	90	14.0	.34	Do.
Eureka	Cork board with asphaltic binder	90	14.5	.32	Do.
Lith	Board containing rock wool, flax, and straw pulp.	90	14.3	.40	Do.
Rock cork	Rock wool block with binder; also called "Tucork."	86	16.7	.37	Do.
Stiff fibrous materials in sheet form:					
Beaver fiber wall board	Laminated board	----	--------	.50	Armour Institute.
Celotex	Sugarcane fiber	90	13.2	.34	Bureau of Standards.
		90	14.8	.34	Do.
Certainteed insulating board.	Laminated board	----	25.9	.39	Armour Institute.

TABLE 55.—*Thermal conductivity of insulating materials*—Continued

(T=mean temperature in degrees Farenheit; D=weight in pounds per cubic foot; K=thermal conductivity in British thermal units per hour, and per square foot of conducting material, with a temperature gradient of 1° F. per inch of thickness)

Material		T	D	K	Authority
Name	Description				
Stiff fibrous material in sheet form—Continued		°F.	*Lb. per cu. ft.*	*B. t. u.*	
Homasote	Paper pulp	70	22.9	0.40	Armour Institute.
Inso board	Wheat straw	68	17.0	.32	Do.
Insulite	Wood pulp	90	16.2	.34	Bureau of Standards.
		90	16.9	.34	Do.
Maftex	Roots of licorice	81	16.1	.34	Armour Institute.
Masonite	Exploded wood fiber	75	18.0	.33	Do.
Thermosote	Wood pulp	70	20.8	.37	Do.
Weatherwood	Hardwood fibers	70	-------	.32	Do.
Cellular gypsum:					
Insulex or pyrocell	Cellular gypsum, dry	90	8	.35	Bureau of Standards.
		90	12	.44	Do.
		90	18	.59	Do.
		90	24	.77	Do.
		90	30	1.00	Do.

TABLE 56.—*Thermal conductivity of miscellaneous building materials*

[T=mean temperature in degrees Fahrenheit; D=weight in pounds per cubic foot; K=thermal conductivity in British thermal units per hour, and per square foot of conducting material, with a temperature gradient of 1° F. per inch of thickness]

Material		T	D	K	Authority
Name	Description				
		°F.	*Lb. per cu. ft.*	*B. t. u.*	
Asbestos mill board	Pressed asbestos	86	61	0.8	Bureau of Standards.
Asbestos wood	Asbestos and cement compressed.	86	123	2.7	Do.
Building brick				3 to 6	Various sources.
Concrete				6 to 9	Do.
Cinder concrete				2 to 3	Do.
Fir sheathing and building paper.		30		[1] 0.7	University of Minnesota.
Fir sheathing, building paper, and pine lap siding.		20		[1] 0.5	Do.
Glass				5 to 6	Various sources.
Granite				13 to 28	Do.
Gypsum fiber concrete	87½ percent gypsum and 12½ percent wood chips.	74	51	1.7	University of Minnesota.
Gypsum tile	Solid	70	52	1.7	Do.
		76	76	3	Do.
Lath and ⅜-inch plaster	Total thickness ¾ inch	70	-------	[1] 2.5	Do.
Limestone				4 to 9	Various sources.
Magnesia (rigid)	85 percent magnesia, 15 percent asbestos.	86	19	0.5	Bureau of Standards.
Marble				14 to 20	Various sources.
Pine lap siding and building paper.	Lap siding 4 inches wide	16	-------	[1] 0.9	University of Minnesota.
Plaster				2 to 5	Various sources.
Plaster board	Gypsum between layers of heavy paper.	70	63	1.4	Armour Institute.
Sandstone				8 to 16	Various sources.
Sheetrock	Gypsum mixed with sawdust between layers of heavy paper (0.39 inch thick).	90	61	[1] 3.6	Bureau of Standards.
Wood [2]				0.3 to 1.1	Various sources.

[1] For the thickness given or for that usual in construction, not per 1-inch thickness.
[2] For different woods see section on physical properties of clear wood.

TABLE 57.—*Conductance and insulating value of sheet materials in thicknesses as sold* [1]

[W=weight in pounds per square foot; L=thickness in inches; C=conductance in B. t. u. per hour, per square foot, and per degree Fahrenheit of temperature difference; $R=1/C$=thermal resistance or insulating value]

Material		W	L	C	R
Name	Description				
		Lb. per sq. ft.	*In.*	*B. t. u.*	*1 B. t. u.*
Soft flexible materials:					
Balsam wool	½-inch house insulation; smooth paper	0.16	0.55	0.48	2.10
Do	½-inch refrigerator insulation, creped paper.	.24	.66	.41	2.47
Do	1-inch refrigerator insulation, creped paper	.32	1.13	.25	4.08
Cabots quilt	Single ply	.14	.35	.72	1.39
Do	Double ply	.18	.48	.54	1.85
Do	Triple ply	.31	.67	.39	2.56
Carinsul	Hair felt between asbestos paper	.58	.60	.46	2.19
Hairinsul	75 percent hair and 25 percent jute	.46	.55	.49	2.05
Do	50 percent hair and 50 percent jute	.42	.51	.51	1.96
Linofelt	½-inch	.41	.67	.42	2.40
Nycinsul	Hair felt between cheesecloth treated with magnesite solution.	.97	.45	.82	1.21
Resisto	Similar to nycinsul:				
Do	Single	.56	.40	.75	1.34
Do	Double	.77	.62	.49	2.05
Salamander	Hair felt, asbestos, paper, and cheesecloth; paper between plys:				
Do	2-ply	.54	.61	.42	2.40
Do	3-ply	.69	.70	.36	2.75
Thermofelt	Jute and asbestos	.42	.51	.72	1.39
Do	Hair and asbestos	.42	.63	.45	2.22
Semiflexible materials:					
Fibrofelt		.66	.58	.56	1.80
Flaxlinum		.61	.56	.56	1.80
Stiff fibrous materials:					
Celotex	Building board	.58	.47	.72	1.38
Do	Railroad insulation board	.64	.58	.59	1.71
Insulite	Wall board	.66	.49	.69	1.46
Do	Insulation board	.80	.56	.60	1.67
Plaster and wall boards:					
Gyplap	Gypsum between layers of heavy paper	2.23	.50	2.60	.38
Sheet rock	Gypsum mixed with sawdust between layers of heavy paper.	1.97	.39	3.60	.27

[1] Based on tests conducted by the Bureau of Standards (Letter Circ. 227). 12 pp. 1927. [Mimeographed.]

Table 55 shows that the differences in the respective heat conductivities of the various light fibrous or cellular insulating materials are not great. In general, the lighter the material per unit volume, voids included, the better is its insulating value per inch of thickness. Stiff fibrous materials in sheet form have considerable structural strength but are somewhat poorer insulators than lighter and looser materials.

Wood is inherently stronger than any of the fibrous insulating materials and being heavier is a poorer insulator. Wood, however, possesses the best insulating properties of any of the basic structural materials now commonly used. There is a considerable range in the insulating value of the different species, the lighter ones having better insulating properties (p. 44).

COMMERCIAL STANDARD FOR FIBER INSULATING BOARD

In recent years fiber insulating board has become of increasing importance in the building industry, especially for house construction. The relatively light board contains a great number of small dead-air

spaces, which give it both thermal and acoustical insulating properties. Although it is primarily a heat insulator, it is also used as a plaster base, and as a substitute for lumber sheathing. Other uses are for sound deadening, and for acoustical improvement in auditoriums and radio-broadcasting stations.

Vegetable fibers of low grade largely form these boards. Groundwood pulp has been widely used in their manufacture, and some well-known boards are still made principally of this material. Other boards contain chemically-pulped wood in mixture with ground wood, and some are made from waste such as old newspapers, which are composed largely of the same mixture. In addition to the insulating boards composed of wood fibers other boards composed of fibers, such as those from bagasse (extracted sugarcane), straw, cornstalks, and licorice roots, are used.

A standard specification for fiber insulating board was adopted in 1932 by a general conference of producers, distributors, and users. The standard establishes definite criteria of the insulating value and other physical requirements that should be possessed by this material.

The standard is a minimum specification for two classes of fiber insulating board designated as "insulating building board" and "roof insulating board." The properties of insulating building board, which is intended for such uses as sheathing, partitions, and plaster base, are governed by requirements of thermal insulation, water absorption, tensile strength, deflection, minimum thickness, plaster adhesion, and expansion with moisture absorption. The properties of roof insulating board, which is used as the name implies, are controlled by requirements of thermal insulation, water absorption, tensile strength, and minimum thickness.

Table 58 gives minimum requirements when fiber board is tested in accordance with the methods that are a part of the commercial standard for fiber insulating board (Bureau of Standards, second reference).

TABLE 58.—*Minimum commercial acceptance requirements for fiber insulating board* [1]

Requirements	Insulating building board	Roof insulating board
Maximum allowable thermal conductivity per hour, per square foot, per degree Fahrenheit, and per inch of thickness, B. t. u.	0.36	0.36.
Minimum thickness, inch	13/32	13/32.
Maximum allowable water absorption, based on initial volume, percent.	5	10.
Minimum average tensile strength, pounds per square inch	175	100.
Maximum deflection of a 4-by-12-inch specimen with 8-inch span, in center loading with a 10-pound weight, loaded for 30 seconds, inches	0.1	
Minimum plaster adhesion, pounds per square foot	600	
Maximum linear expansion, percent	½	
Standard sizes:		
Boards, inches	48 by 72, 48 by 84	22 by 47.
	48 by 96, 48 by 108	24 by 47.
	48 by 120, 48 by 144	24 by 60.
		30 by 47.
Lath, do	16 by 48, 18 by 48	
	24 by 48	

[1] U. S. Department of Commerce, Bureau of Standards, fiber insulating board, Commercial Standard CS42-32.

HEAT LOSS THROUGH DIFFERENT TYPES OF WALLS

The relative heat losses through different types of walls due to transmission (National Lumber Manufacturers' Association, Bureau of Standards Circular 376, and National Committee on Wood Utilization) and not air leakage are given in the following tabulation, which is based on tests conducted by the Bureau of Standards (Van Dusen and Finck). Heat losses for walls in which special insulation is included have been computed from test data on the individual parts of the wall. Other figures are from tests on complete wall sections.

Wall type	*Heat loss*
Frame wall, wood siding, building paper, wood sheathing, wood lath, and plaster	0. 190
Frame wall, wood siding, building paper ½-inch rigid insulating board sheathing, wood lath, and plaster	. 175
Frame wall, wood siding, building paper, wood sheathing, ½-inch rigid insulating board plaster base, plaster	. 156
Frame wall, wood siding, building paper, wood sheathing, wood lath, and plaster, with ½-inch felt or quilt insulation between studs	. 125
Frame wall, 4-inch brick veneer, building paper, wood sheathing, wood lath, and plaster	. 175
Frame wall, 4-inch brick veneer, ½-inch rigid insulating board sheathing, wood lath, and plaster	. 160
Frame wall, 4-inch brick veneer, building paper, ½-inch rigid insulating board plaster base, and plaster	. 145
Frame wall, 4-inch brick veneer, building paper, wood sheathing, wood lath and plaster, with ½-inch felt or quilt insulation between studs	. 118
8-inch brick wall, ¾-inch plaster on brick	. 420
8-inch brick wall, ¾-inch plaster on wood lath, furred	. 280
8-inch brick wall, plaster on rigid insulation board, furred	. 208
8-inch hollow building-tile wall, stucco exterior finish, ¾-inch plaster on tile	. 280
8-inch hollow building-tile wall, stucco exterior finish, ¾-inch plaster on wood lath, furred	. 210
8-inch hollow building-tile wall, stucco exterior finish, plaster on ½-inch rigid insulating board, furred	. 167

The values in the tabulation were computed by the equation $T=\frac{1}{1+R}$ and correspond to a mean temperature of 50° F. T is the transmittance; R is the resistance to heat transfer and is numerically equal to $1/c$ where c is the conductance in British thermal units per hour per square foot per degree Fahrenheit temperature difference between the surfaces of the wall. The total resistance of the two surfaces of a wall is taken as equal to 1° per unit heat flow (1 British thermal unit per hour per square foot). This is believed to be a reasonably good average value for ordinary temperatures and air velocities. The resistance of a wall figured from air to air will then be one plus the resistance from surface to surface.

AIR INFILTRATION

Air infiltration exclusive of that entering around loose sash or doors may also be an important factor affecting heat losses (U. S. Federal Board for Vocational Education and National Committee on Wood Utilization). Table 59 gives the results of tests conducted at the University of Wisconsin by Larson, Nelson, and Braatz on the air leakage per square foot for a 15-mile wind pressure for dif-

ferent types of walls. These tests show the importance of a suitable building paper in reducing air leakage through frame walls. Tight roof sheathing materially reduces air leakage, and where building paper is used between shingles and sheathing the leakage is negligible. The increased insulating value of the tight sheathing and the value of the paper in resisting air infiltration mean a warmer attic and result in less heat loss from heated rooms beneath.

TABLE 59.—*Air infiltration through frame walls* [1]

[Wind velocity 15 miles per hour]

Description of construction				Air infiltration per hour per square foot of wall
Sheathing	Building paper	Siding	Inside construction	
				Cubic feet
1 by 6 inch air-dried dressed and side matched.	None	None	None	12.3
Rigid insulating board (coarse fibered).	do	do	do	16.1
Rigid insulating board (fine fibered).	do	do	do	9.1
None	do	Corrugated steel	do	27.3
1 by 4 inch boards on 5 inch centers.	do	16-inch shingles, 5 inches exposed.	do	69.5
1 by 8 inch air-dried shiplap	do	do	do	15.3
1 by 6 inch air-dried shiplap	Building paper	16-inch shingles, 7½ inches exposed.	do	.2
1 by 6 inch air-dried dressed and side matched.	do	1 by 6 inch drop or bevel siding.	do	.2
1 by 6 inch air-dried dressed and end and side matched.	do	None	do	.3
None	None	do	Wood lath and 3 coats gypsum plaster.	.2
Do	do	do	Wood lath, 3 coats gypsum plaster, and wallpaper.	.1
Do	do	do	Metal lath and 3 coats gypsum plaster.	.2

[1] Based on tests conducted by the University of Wisconsin.

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